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M E M O R A N D U M

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TO: Dean D. W. Karger, School of Management
Dean Stephen Wiberley, Graduate School

FROM: V. L. Parsegian, Rensselaer Professor

SUBJECT: Thesis of Commander Thomas B. Thamm

I have read the thesis titled Nuclear Power and The Merchant Marine Crisis, submitted by Tom B. Thamm, Commander, U. S. Navy, in partial fulfillment of requirements for the degree of Master of Science. We have discussed this study on earlier occasions as well.

In my opinion, the thesis as submitted is entirely acceptable and probably represents a substantially larger effort and contribution than is normally achieved for Masters level work.

Very truly yours,

NUCLEAR POWER

AND

THE MERCHANT MARINE CRISIS

by

Tom B. Thamm
Commander, U.S. Navy

A Thesis Submitted to the Faculty
of the Department of Management
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

Approved:

____

V. Lawrence Parsegian, Ph.D.
Adviser

Rensselaer Polytechnic Institute
Troy, New York

June, 1969

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NOTE:

Appendixes A, B and C are referred to in the text of the attached thesis but are not appended due to the inability to reproduce them. They are not essential to an understanding of the subject matter.

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The author gratefully acknowledges the professional assistance and personal encouragement of Dr. Harry Benford, distinguished Chairman of the Department of Naval Architecture and Marine Engineering, College of Engineering of the University of Michigan at Ann Arbor. Dr. Benford is internationally recognized for his preeminence in the field of marine engineering economics and he is the author of many prominent works in that field. His patient, lucid and good-humored replies to a barrage of requests for information and explanations of fundamental principles can only be fully appreciated by one who is not a naval architect.

Rather than repetitiously refer to his works, the author here acknowledges that with Dr. Benford's kind permission, Part III of this study has drawn heavily and in many instances directly on the concepts and formulations of the first four references cited in Part VIII.

The author also gratefully acknowledges the counsel and assistance of Dr. V. Lawrence Parsegian of the Rensselaer Polytechnic Institute at Troy, N.Y. who was adviser to this study. Dr. Parsegian has served as Dean of the School of Engineering and Professor of Nuclear Engineering at the Institute and presently holds the distinguished Chair of Rensselaer Professor. Dr. Parsegian is a renowned figure in the field of atomic energy both in the United States and abroad and has served in many important capacities in this field at the state, national and international level. He is the author of many important articles and texts in the field of science.

FOREWORD

In 1819, the United States ship S.S. SAVANNAH made the first crossing of the Atlantic assisted by a small steam engine. It was a daring enterprise sponsored by American shipping interests. This first venture with a new technology proved to be a commercial failure and the engine and boiler were removed to make room for additional cargo. SAVANNAH ended her days as a conventional sailing ship.

Twenty years later, the British ship SIRIUS crossed the Atlantic propelled entirely by steam. Thus began the development of the powerful British steam propelled merchant fleet and seventy-five years of maritime dominance.

Now one hundred and fifty years later, it may be that history is repeating itself.

ABSTRACT

The dominant purpose of this study is a realistic examination of the economic feasibility of merchant ship nuclear power and its relevance to the present state of crisis in the merchant marine of the United States.

The study reviews the origins and current status of U.S. maritime law, its archaic system of direct and indirect subsidies which tries to maintain U.S. shipping interests on a competitive basis with foreign nations, and the failure of this system as evidenced by the post-war decline and present abject state of our merchant fleet. It underscores the principal causes for maritime decay as high costs of construction and operation under the U.S. flag, labor strife, antiquated legislation and the failure to agree on a course of remedial action. It is suggested that the merchant marine of the United States which today carries only 7% of our total import and export trade, be revitalized in the interest of national necessity.

An examination of the current state of world merchant ship nuclear power is conducted and it is concluded that leadership in maritime nuclear propulsion has passed into the hands of other nations. A representative sample of the forces that control the future of merchant ship nuclear power in the United States is presented. This sample indicates that the positions and attitudes of these forces are in conflict and that the result is complete stagnation of a merchant ship reactors program.

The study then describes the construction and operation of a mathematical model of a hypothetical, but realistically configured contemporary merchantman in which all costs of construction and operation are contained. The model is operated under identical conditions in both a conventional and nuclear mode and the results of operations are economically compared.

A sensitivity analysis of realistic variables is conducted to determine those operational factors that control the competitive environment between nuclear propulsion and oil fired ships. The results of operation and sensitivity analysis find that high power, long trade routes, short turnaround time and high reactor utilization are the requirements for competitive maritime nuclear power and that these requirements are not met in the ship under study.

A review of recent estimates and forecasts for the supply and demand of fossil fuels is conducted. As assessment of these forecasts indicates that the world bank of fossil energy is being rapidly depleted, particularly in the case of oil. The importance of these diminishing reserves to the transportation industry, with particular emphasis on ocean commerce is explored.

The study concludes that there is no competitive basis for nuclear propulsion on contemporary merchant ships since the conditions for economic parity with conventional installations cannot be realistically met. A review of current changes in the maritime industry is made, and it is suggested that a new concept in total transportation is emerging which sees the ship as a subsystem rather than an economic entity. This review suggests that the requirements of this new maritime concept are moving in a direction that will meet the conditions for competitive merchant ship nuclear power.

A conditional merchant ship nuclear power program is recommended and described. The program calls for government support for a research and development program that will result in a packaged nuclear steam supply system for installation in a series of selected ships whose characteristics meet the conditions for competitive nuclear power. The basic conditions for government support are the acceptance of standardization of design to achieve the economies of volume and that shipowners demonstrate that a need exists for ships that meet the conditions for economic parity.

PART I.

INTRODUCTION AND HISTORICAL REVIEW

A. Preface

The interface between nuclear propulsion and its potential application to commercial marine use cannot be studied in isolation from pertinent history. The purpose of this part is to acquaint the reader with the basic background of United States maritime law so that subsequent sections of this paper are put in proper context.

B. The U.S. Merchant Marine Act of 1936

The constitution of U.S. maritime policy is the Merchant Marine Act of 1936. The law was passed because shipbuilding and wage costs had priced the privately owned U.S. merchant fleet out of competition with foreign flags. In an attempt to stem the decline of the U.S. Merchant Marine, the Act of 1936 introduced a system of differential subsidies for the construction and operation of cargo liners on specified essential trade routes.

But the Merchant Marine Act served a broader purpose than the surface aspects of economic competition with foreign nations. It declared the maritime policy of this country to be that the United States should never be at the mercy of foreign ships or foreign shipyards. It recognized that an efficient and economic national merchant fleet and shipbuilding industry were essential to our defense posture. Its concepts called for a U.S.-built, U.S.-owned and U.S.-manned fleet of merchant ships capable of transporting this country's domestic waterborne commerce, a substantial portion of its foreign trade and supporting the armed forces as an effective auxiliary in time of national crisis.[5*]

Revision of the Merchant Marine Act is the center of an epic controversy between and among elements of government, shipowners and shipbuilders in the United States today. It is not the purpose of the Act which is contested, but its provisions for subsidy.

*Throughout this thesis, superscript numbers refer to the similarly numbered items in PART VIII, LITERATURE CITED, used in support of statements preceding the superscript number.

C. Subsidy Provisions of the Merchant Marine Act

The range and variety of government aids to the maritime industry is complex and no purpose will be served by a detailed presentation in this study. The basic subsidy provisions of the Merchant Marine Act of 1936, as amended, are as follows:[6]

1. Construction Subsidy

Under the authority of Title V, provision is made for a construction differential subsidy for ships engaged in foreign commerce. This subsidy is limited to 55% for cargo liners and 60% for passenger ships. The purpose of the subsidy is to enable American shipowners to construct ships in the United States on a parity with their foreign competitors. Funds appropriated for this purpose amounted to $143,000,000.00 in 1968.[5]

2. Operating Subsidy

Like the construction subsidy, the operating differential subsidy is given to ship operators to place American vessels on a par with those of foreign competitors. The amount of this subsidy is based on the difference between the fair and reasonable cost of insurance, maintenance, repairs, wages and subsistance and the estimated cost of the same items if the ship were operated under foreign registry. Any profits made in excess of 10% are recaptured by the government to the extent of 50%. Funds appropriated for this purpose amounted to $200,000,000.00 in 1968.[5]

3. Tax Benefits

Section 511 of the Act provides for the establishment of construction reserve funds. Shipowners may deposit proceeds from the sale or indemnities from the loss of ships into this fund. Any gain on such a transaction is tax-free if the deposits are used for the construction, reconstruction or acquisition of another ship within a specified time. The allowable depreciation on the new ship is reduced by the amount of gain.

Operators receiving operating differential subsidy obtain tax concessions for the deposit of earnings into res-

erve funds. Under the authority of section 607(h) of the Act, all such deposits of earnings, including capital gains, are tax deferred. Thus, so long as an operating differential subsidy agreement remains in effect and no earnings are withdrawn for purposes other than the construction, reconstruction of acquisition of a new ship, these " tax-deferred" earnings are in effect, tax exempt. If earnings are withdrawn for any other purpose, they are taxable as if earned in the year of withdrawal.

4. Other Supports

Additional aid is granted to U.S. shipowners in the form of new investment tax credits, government insurance of commercial loans and mortgages for the construction or reconstruction of ships, direct loans for subsidized construction at attractive interest rates, acquisition by the government of privately owned obsolete vessels in exchange for an allowance of credit to the shipowner or shipbuilder on new ships and preferential routing of government-owned or financed cargoes on U.S.-flag commercial ships.

The reader now has some appreciation for the awesome extent of government support to the United States maritime industry. The scope of this aid can be further appreciated by comparison to the assistance provided by other prominent maritime nations to ships carrying their flag. This data is presented in Table I on the following page.

TABLE I

SUMMARY OF GOVERNMENT AIDS TO MARITIME INDUSTRIES

	Direct		Indirect			
	Operating Subsidy	Construction Subsidy	Tax	Depreciation	Loans & Interest	Other
DENMARK				X	X[1]	
FRANCE	X	X		X	X	X
W. GERMANY			X	X	X	X
GREECE			X			X
ITALY	X	X	X	X	X	X
JAPAN	X	X	X	X	X	X
NETHERLANDS				X	X	X
NORWAY	X[1]		X	X	X	X
SWEDEN	X[1]	X[1]	X	X	X	X
U.K.	X[1]		X	X	X	X
U.S.	X	X	X	X	X	X

1 Domestic Trade only.

D. The Failure of the United States Maritime Program

Despite the injection of nearly five billion dollars in subsidy money during the past 30 years,[7] the maritime program of the United States is bankrupt by any standards. Depending on viewpoint, this failure is because or in spite of the concept of the Merchant Marine Act of 1936.

1. The Present State of the U.S. Merchant Marine

The United States has a recurrent history of post-war maritime decay and there is no more eloquent testimony to the magnitude of this American tragedy than a review of the familiar pattern that emerged from World War II. When the U.S. entered the hostilities, our merchant marine base was totally inadequate to the logistic need. A merchant fleet was constructed on a crash basis at a staggering cost. These ships and the men who sailed and died in them performed an heroic task. Following the war, the usual sacred oaths were taken that this must not happen again. It has.

The U.S. active flag fleet which consists of privately owned ships and government vessels not in the National Defense Reserve Fleet has dwindled from 1617 ships in 1950 to 1167 in 1966. This represents a decline of from 14.1% of the world fleet to 6.8%. Table II shows the number of U.S. ships and their percentage relative to the world fleet during this period:

TABLE II[8]

POST WAR DECLINE OF THE U.S. MERCHANT MARINE

	1950	1966
TANKERS	457 (21.5%)	277 (7.7%)
BULK CARRIERS	54 (9.6%)	57 (2.7%)
FREIGHTERS	1049 (13.6%)	804 (7.5%)
PASSENGER/CARGO	57 (5.2%)	29 (3.4%)
TOTALS	1617 (14.1%)	1167 (6.8%)

By contrast, some of our world war friends and foes have had a different post-war experience as indicated by Table III:

TABLE III[8]

REVIVAL OF PREWAR MARITIME POWERS

	1950	1966
JAPAN	387 (3.4%)	1405 (8.1%)
U.S.S.R.	432 (3.8%)	1343 (7.8%)
NORWAY	959 (8.3%)	1356 (7.8%)
W. GERMANY	174 (1.5%)	860 (5.0%)
GREECE	218 (1.9%)	952 (5.5%)

A comparison of the U.S. merchant marine with that of the U.S.S.R. today is an enervating experience. The number of U.S. active flag ships has now reduced to some 1115 ships[7] and more than 90% of these are 20 years old or older.[9] These ships are carrying little more than 7% of the total United States foreign waterborne import and export trade.[5] Our present rate of ship construction is about 12 per year. At that rate, the U.S. will have an active fleet of some 357 ships by 1972.[5]

The number of merchantmen flying the ensign of the Soviet Union has grown to over 1400 ships and of these, approximately 58% have been built since 1958.[7] The U.S.S.R. is now building ships at the rate of about 100 annually.

Russia had declared a shipping war on the west and there is little doubt that she means to win. One of her initial targets is the Europe-Australia trade and passenger routes. Russian merchant ships are offering European wool importers shipping rates 15% below competition. Soviet passenger fares are about $150 lower than the lowest price charged by the British and Western Europe lines. Ironically, some of these ships are homeward bound after having unloaded war materials on the docks of Haiphong.[10]

Despite previous predictions by the Department of Defense to the contrary, 98% of our war materials to Viet Nam and two-thirds of our troop strength in that area have been transported by sealift.[5] Our merchant fleet has not been equal to the task. To provide today's military sealift requirements, a polygenetic fleet has been assembled consisting of some 144 ships from the aging National Defense Reserve Fleet (NDRF), 27 Military Sea Transportation Service (MSTS) freighters, 25 MSTS tankers and about 20 foreign flag tankers in addition to about 45% of the privately owned U.S. general cargo fleet and 25% of the U.S. private tanker fleet.[6]

Commenting on the adequacy of the NDRF to meet Viet Nam sealift requirements, the Maritime Administration stated:

"...it is more meaningful to say that unless the reserve fleet is replaced, there won't be a reserve fleet due to its age and state of repair."

2. <u>The Present State of the U.S. Shipbuilding Industry</u>

From the foregoing, it should come as no surprise to learn that the United States is not the leader in world ship construction. Estimates of her actual position vary from 8th[12] to 14th.[5] In any event, it is not position on a scale that matters; what counts is how much business you are doing. Lloyd's Register of Shipping sets present world shipyard orders at a record high of 40,632,120 tons. The U.S. received only 3% of these orders. The world leaders in shipbuilding today are indicated in Table IV:

TABLE IV

WORLD SHIPBUILDING LEADERS

	Shipyard Orders in Hand (1968)[12]
JAPAN	17,646,189 tons
SWEDEN	3,001,233 tons
W. GERMANY	2,587,923 tons
FRANCE	2,456,388 tons
U.K.	2,094,000 tons

E. The Causes of Failure

There is a plethora of reasons why the maritime program of the United States has failed and each is worthy of a dissertation. This study will confine itself to a brief discussion of the principal causes.

1. High Costs

The U.S. Merchant Marine is unable to compete on the world market now for the same reason it could not in 1936. It costs about twice as much to build and operate a ship under the U.S. flag as under foreign registry. An example will serve to illustrate the point. On 1 November, 1968, contracts were signed for the construction of three common carrier freight ships by the General Dynamics Corporation for the Lykes Brothers Steamship Company, Inc. Scheduled for completion in 1971, the construction price is $32,617,333.00 each. The government is paying for 55% of this cost under the construction differential subsidy provisions of the Merchant Marine Act of 1936. Lykes president, Frank A. Nemec, said the cost for constructing these same ships in Japan would have been about $13.5 million each, but the Lykes Company is building them in the United States to be eligible for continued subsidy.[13] By "continued subsidy", Mr. Nemec is not referring to the 55% already committed by the government to the construction cost of these ships; he is undoubtedly referring to the operating differential subsidy his ships will be eligible for by virtue of being built in the United States. The law prohibits foreign built ships from eligibility for the operating subsidy.

Unfortunately, the high cost of U.S. involvement does not end with construction. For the twenty to twenty-five years of the ship's life after completion, she faces the additional competition of operating costs. An example of the degree of this competition is presented in Table V on the following page.

TABLE V[8]

COMPARATIVE COST AND PERCENT (%) OF TOTAL COST OF OPERATING A 47,000 DEADWEIGHT TON BULK CARRIER UNDER SELECTED REGISTRIES

	ANNUAL COST		
Flag:	UNITED STATES	FOREIGN	FOREIGN
Crew:	American	Japan	British
Crew*1	42	45	44
Repair Days	20	20	20
Operating Days	345	345	345
	%	%	%
Payroll	$612,000 (40)	$184,000 (29)	$232,000 (31)
Depreciation*2	510,000 (33)	250,000 (39)	250,000 (33)
Repairs	154,000 (10)	88,000 (14)	88,000 (12)
Overhead	50,000 (3)	30,000 (5)	30,000 (4)
Stores and Provisions	84,000 (5)	24,000 (4)	88,000 (12)
Insurance	105,000 (7)	47,000 (7)	47,000 (6)
Other	19,000 (1)	19,000 (3)	19,000 (3)
Total Annual Cost	1,534,000	642,000	754,000
Cost per Operating Day	$4,446	$1,861	$2,186

*1 Typical modern but non-automated bulk carrier.

*2 Straight line basis over a 20 year period.

2. Labor Strife

The cost and conduct of American maritime labor is a pervading factor in the failure of the maritime program. As shown in Table V, the wage differential between American seamen and those of other nationalities is staggering; for one of the comparative examples, the wages paid to the U.S. crew nearly equal the total annual operating cost of the other.

After returning to her service facilities in Galveston in 1963, labor disputes broke out on the nuclear ship N.S. SAVANNAH. These disputes centered on pay differentials between the engineering and deck departments. The strike could not be settled. As a result, the ship was immobilized for a year. The government was forced to start all over again with a new General Agent for operation of the ship. Contracts had to be negotiated with different maritime unions and a new crew had to be trained to operate the ship.[14] During the second year of experimental operation, 1966-1967, the average wage paid to the 66 man crew of SAVANNAH exceeded $18,000.00.[14]

The United States had demonstrated the peaceful use of the atom to the world through operation of the SAVANNAH; it had demonstrated something else to prospective nuclear merchant ship operators in this country.

In a statement before the Subcommittee on Merchant Marine of the U.S. Senate on 10 May 1968, the Secretary of Transportation, Alan S. Boyd, summed up the problem of maritime labor:

"If the U.S. merchant marine is to respond to the needs of the American shipper, both management and labor must work closely to eliminate the recurring interruptions in service caused by work stoppages. Such interruptions destroy confidence in U.S.-flag carriers. Shippers consequently turn to foreign-flag vessels for their needs.

A series of labor-management agreements, negotiated in 1965 to help assure wage stability, have in practice accomplished the opposite. Under these agreements, if the members of one union receive a wage increase or other benefit, other maritime unions can reopen their contracts through a 'me too' clause and demand arbitration to obtain a matching increase. By the time several unions have received such increases, the first union is in a position to assert that it is once again behind the others - and the cycle starts all over again."

" Because of this practice, employment costs in the industry have risen more than 30% since 1965. These costs increase Federal expenditures through the operating subsidy program and shipping costs of Government cargoes. They diminish the ability of the U.S. merchant marine to compete with foreign fleets. Not only do spiraling employment costs threaten the industry with economic ruin, they imperil the American public as well, for they have a shattering impact on our Nation's wage-price stabilization objectives."

3. Outmoded Legislation

When the Merchant Marine Act of 1936 was drafted by Congressman Joseph P. Kennedy, American-flag ships were carrying about one-third of U.S. foreign trade. One of the expectations of the legislation was an increase in this share to about 50%. One of the important reasons that we are carrying little more than 7% today is not the faulty vision of the framers of this law, but rather the failure of succeeding governments to maintain this legislation in an up-dated condition.

One of the fundamental concepts of the Act of 1936 was that its provisions extended only to cargo liners engaged in foreign commerce. There was justification for this position. In the 1930's there was no American dry cargo bulk carrier fleet; we were marginal exporters of the great bulk staples of grain and coal. In addition, there was only the barest beginning of an independent tanker fleet. This concept was further reinforced when in 1937, Chairman Kennedy reported that a study of tramp shipping indicated that it would soon disappear in favor of cargo liners. The Act took no cognizance of government cargo since in the 30's, there was no important movement of government commodities in commercial ships.

Conditions changed. In 1966, dry bulk cargo in our foreign trade amounted to some 206 million tons. Tanker cargoes in foreign trade increased to 147 million tons. Today, the Department of Commerce estimates that by 1985, dry bulk cargoes will rise in volume to 381 million tons and tanker cargoes to 235 million tons. The volume of

government cargoes has become astronomical. The U.S. government is today the world's largest shipper.[5]

Yet, despite these major changes in the U.S. maritime environment, the basic clauses of the Act of 1936 remain essentially unchanged. Cargo liners are still the only ships eligible for construction and operating differential subsidies. The failure to change the law to meet changing condition has had a very dramatic effect. Since they are not eligible for subsidy under American law, U.S. owners of bulk carriers and tankers have sought the more favorable economic climate of "flags of convenience" - Panama, Liberia and Honduras.

Today, Liberia registers 1429 ships accounting for 8.3% of the world fleet. This is larger than the U.S. active fleet. Table VI shows the number and type of ship under American management in the PanLibHon registry:

TABLE VI[8]

U.S. OWNED SHIPS UNDER FLAGS OF CONVENIENCE

	Dry Cargo	Tankers	Totals
LIBERIA	169	185	354
PANAMA	17	93	110
HONDURAS	10	0	10
TOTALS	196	278	474

Unfortunately, it cannot be reported that correction of this failure is imminent; both House and Senate Bills introduced for this purpose during the last session of Congress failed to be enacted. Versions of both these bills were first introduced in 1963. Is it possible that "America's leaders have found the subject of a merchant marine to be too complicated for correction"?[15]

4. The Other Side of Subsidy

To objectively examine the causes for failure of the U.S. maritime program, it must be reported that there is a body of opinion that believes that the concept of subsidization contained in the Act of 1936 is a direct cause of failure. This opinion feels that merchant marine and shipbuilding industry dependence on subsidy has fostered outmoded and uneconomical practices. Certainly it is no surprise that the mainstream of this thinking is the agency that must pay the subsidy.

Secretary of Transportation Boyd, representing the Johnson Administration, made the case for a new look at government support:

"Enduring through the years as a tradition, the merchant marine has declined as an industry. Its decline parallels its increasing dependence on Government support through subsidies of one kind or another. Subsidies - direct and indirect - have been a compromise answer to a difficult situation. They have prevented both the death and the nationalization of the merchant marine."

"The subsidy system itself is in clear need of reform. Instead of encouraging innovation and productivity, the system focuses attention on the subsidy dollar as a source of income. A new system must be found that will induce the industry to take full advantage of advancing technology, management ingenuity, and the resources of a skilled labor force.

The Government now subsidizes the ship operator to make up the differences between certain elements of his operating costs and those of his foreign competitors. This process has proven inadequate and unsound. For example: It requires a network of Government auditors in the steamship company's offices, as well as an overseas staff of Government employees to provide estimates of foreign operating costs.

It imposes cumbersome administrative procedures upon the operator, who is forced to make a detailed justification for each of his subsidy-related costs.

It requires strict adherence to trade routes and restricts the operator from taking advantage of shifting market conditions.

It gives the operator little incentive to hold down costs, since increases are borne by the Government." 6

Although there is probably much validity in the previous Administration's position, Mr. Boyd did not make it clear how reduction of subsidy would"encourage innovation and productivity" while going out of business.

5. The Failure of Agreement

Last, but certainly not the least in importance is the failure of the government, shipowners, shipbuilders, maritime labor and all manner of merchant marine interests to agree collectively or individually on what must be done to solve the maritime problem. The harangue of proposal and counter-proposal is seemingly endless. The exigency of the matter requires that it not be endless. With each year of indecision and uncertainty, our merchant marine declines and we are becoming more and more dependent on ships of foreign origin to carry our ocean trade.

F. The Crisis

The United States Merchant Marine faces a double crisis - one of condition and one of decision.

The crisis of condition consists of simple definition: block obsolescence of our merchant fleet and increasing dependence on ships of foreign origin to transport the stuff of our ocean commerce.

The crisis of decision is more difficult. First, we must decide whether to correct the state of our merchant marine by renovating the maritime program or whether to repeal the principle of the Merchant Marine Act of 1936 either by deliberate legislative act or by failure to act at all. While this latter course has not been overtly taken, the failure to agree on and execute a plan of action has had the same effect.

This paper assumes that the decision to rebuild the merchant marine industry will be an affirmative one. This assumption is based on three factors:

1. The national interests of a country that must import 66 of 77 strategic materials[16] and which is isolated from its allies by the world's oceans demand it.
2. The future logistic needs of an exploding global population leaves no realistic alternative for the physical and economic safety of our people.
3. The present administration is committed to a revitilization of the maritime industry.

Second then, the nation must decide how to rebuild. This is the principle thrust of this study. This paper will seek to establish that the choice is between an established but short-lived technology and a new but expensive one and that in the final analysis, the choice is not one of technologies, but vision.

G. The Objectives of this Study

The dominant purpose of this work is an objective, realistic appraisal of the economic feasibility of merchant ship nuclear power. This investigation will take the following form:

1. An examination of the [illegible]ent status of world merchant ship nuclear power and a representative sampling of the attitudes and positions within the United States that control the choice between conventional or nuclear reconstruction of our merchant marine.
2. The construction, description and operation of a mathematical model of a hypothetical, but realistically configured contemporary merchant ship in both a conventional and nuclear mode.
3. An objective examination of the comparative economics that result from operation of the model under identical circumstances.
4. The conduct of a sensitivity analysis of those factors which are realistically variable and which bear directly on the choice between the alternatives.
5. The review of estimates and forecasts for the supply and demand of fossil fuel energy and an assessment of their meaning to the future of maritime commerce.
6. To suggest in summation how the decision between reconstruction alternatives should be made to best serve the national interest.

PART II.
STATUS, POSITIONS AND ATTITUDE ON MERCHANT SHIP NUCLEAR POWER

A. The Present Status of World Merchant Ship Nuclear Power

1. United States

N.S. SAVANNAH was launched by the New York Shipbuilding Corporation on 21 July, 1959. When SAVANNAH was turned over to the government's general agent for operation, the Maritime Administration and the Atomic Energy Commission had spent $55 million dollars. From February 1962 until August 1968, SAVANNAH travelled more than 333,000 miles and burned 122 pounds of uranium, the equivalent of 21,500,000 gallons of oil fuel. She completed her first shuffle refueling at the special servicing complex owned by the government and operated by the Todd Shipyards Corporation in October 1968 at Galveston, Texas. Now returned to sea, SAVANNAH remains the United States' sole operating application of commercial marine nuclear propulsion. No follow-on ships are being constructed and none are in planning.[13,17,18]

2. West Germany

Europe's first nuclear powered freighter, OTTO HAHN made her first voyage on 12 October 1968. She is a 25,900 ton iron ore carrier, smaller and slower than SAVANNAH, but with an advanced reactor built by the Deutsche Babcock and Wilcox, Oberhausen (not connected with the U.S. B&W) and Interatom. Her principal mission is the training of West Germany's cadre of nuclear ship crews. She will carry ore from Narvik, Norway to Bremen, Rotterdam and other routes to offset her construction cost of $13.8 million dollars. OTTO HAHN is 564 feet long with a beam of 77 feet and a draft of 30.2 feet. Her cruising speed of 15.7 knots is provided by steam driven turbines of 10,000 SHP. German reactor engineers forecast that in the next decade, 50,000-100,000 SHP nuclear merchant ships will be competitive with conventional installations.[13,18]

3. Japan

On 27 November 1968, the keel was laid for Japan's first atomic powered merchant ship at the Tokyo works of Ishikawajima-Harima Heavy Industries Ltd. The Japan Nuclear Ship Developement Agency plans to complete the ship by 1972; construction cost is reported at $15.6 million dollars. The 36 megawatt pressurized water reactor will be manufactured by the Mitsubishi Atomic Power Industries. Like OTTO HAHN, the Japanese ship will serve in the dual capacity of freighter and training ship. The ship will be 429 feet in length with a beam of 63 feet and a depth of 43.5 feet. A 10,000 SHP steam turbine will drive the ship at a cruising speed of 16.5 knots. It is reported that the Japanese governement will pay for three-quarters of the building cost and industry the remainder. Japanese government agencies have expressed interest in constructing a nuclear powered container ship able to carry 1,000 containers at 30 knots in the mid 1970's. [13,18,19]

4. Italy

A cooperative consisting of the Italian Navy and the National Commission for Atomic Energy has agreed to construct an 18,000 ton nuclear merchant ship to be designed, financed and operated by the Navy. Tentatively named ENRICO FERMI, this 20 knot ship will be propelled by 22,000 SHP steam turbines supplied by a pressurized water reactor. One of her primary missions will be the training of civilian seamen in nuclear power. The ship will be 574 feet in length with a beam of 77 feet and a depth of 44 feet. [18]

There has been considerable debate in the United States as to whether we have lost the lead in maritime nuclear power by failure to follow-up SAVANNAH with second generation ships. The activities of the three countries described above make it clear there is little left to debate about. Paradoxically, it will be remembered that some 25 years ago, the three countries above were referred to as the "axis powers". While the implication of political alignment is gone, the phrase seems appropriate in a new sense.

B. Positions and Attitude on Merchant Ship Nuclear Power in the United States

There is a triumverate of power in the United States that controls the destiny of commercial marine nuclear propulsion. It is necessary to understand the mood and interests of these forces in order to assess the prospects for merchant ship nuclear power.

1. The Government

a. Congress

In 1963, Congressman Edward A. Garmatz, Chairman of the House Subcommittee on Merchant Marine introduced merchant marine reform legislation (H.R. 1071) that included strong support for merchant ship nuclear power. A companion bill was introduced in the Senate by Senator Beall the following year (S.2795).[20]

This legislation amended the Merchant Marine Act of 1936 by adding a new Title X. The purpose of the new title was to foster "the development, construction, and operation of privately owned nuclear powered merchant ships whose designs embody significant departures from the designs of existing nuclear powered merchant ships which may lead to reduction of the cost of constructing and operating future nuclear powered merchant ships." [21]

Significant design departures included, but were not limited to:

(1) reactor systems not yet demonstrated aboard ship which have potentially greater economic efficiency,

(2) decreased weight per power output,

(3) extension of power range appreciably above, or reduction of power range below, the power ranges of existing nuclear powered merchant ships,

(4) utilization of multiple reactor systems,

(5) major modifications in design, arrangement, fabrication or operating techniques, and

(6) engineering of an existing reactor concept into a new ship type not previously adapted to nuclear power.[21]

Even a casual review of these requirements indicates that only slight movement in the state of the art over that embodied in SAVANNAH would be sufficient to qualify for the aid provisions of this legislation.

Providing the prerequisites are met, the Secretary of Commerce is authorized to:

(1) pay all or part of the excess of development costs, including first fuel core, over the cost of developing a comparable conventional ship and,

(2) pay all or part of the excess of construction costs in the United States, including first fuel core, over the cost of foreign construction of a comparable conventional ship.

In addition, the legislation authorizes the Secretary to assist in the training of crews, plan and design shore service facilities, provide appropriate classified information, provide government research and development facilities, design review services, ship construction inspection services and ship operation advisory services.[6]

This legislation put prospective nuclear powered merchant ship operators on a par, or perhaps even slightly ahead of, conventional shipowners.

These bills were not enacted and have been re-introduced and defeated during each subsequent session of Congress. They have been introduced again during the present session, and one of the House versions (H.R. 782) in included in this study as APPENDIX A for the interested reader.

Although the attitude of the present administration with respect to merchant ship nuclear power is not known, there seems to be little confidence for passage of the current legislation.

b. Administration

On 20 May 1968, hearings were begun before the Subcommittee on Merchant Marine of the U.S. Senate on S.2650, a bill to amend the Merchant Marine Act of 1936 and other statutes to provide a new maritime program. S.2650 contained provisions for merchant ship nuclear support as described in the previous section of this study. Alan S. Boyd, Secretary of Transportation, represented the administration. Following a reading of the proposed legislation, Secretary Boyd introduced the administration's version of the bill. It did not contain the word "nuclear". The only allusion to the subject of merchant ship nuclear power was contained in Mr. Boyd's prepared statement:

> "There is serious doubt as to the attractiveness and wisdom of proceeding with a broader nuclear ship program at the present time. It appears that power reactors of the relatively small sizes required for merchant ship propulsion will continue to be noncompetitive with oil over the foreseeable future." [6]

No substantiating data were presented for this position, thus the administration's position must be taken as given.

c. Atomic Energy Commission

Some history and much concentration is required to understand the Commission's stand on maritime nuclear power. In hearings before the Joint Committee on Atomic Energy in 1965 on the development, growth and state of the atomic energy industry, the position of the AEC towards maritime nuclear power was presented by Commissioner Ramey:

> "We believe that the Commission has now embarked on a realistic and readily understandable program.
>
> We have proposed a two-prong approach. The first is the Commission's research and development program for an advanced civilian maritime reactor plant facility and, the second, is our cooperation with the Maritime Administration on their nuclear shipbuilding program.
>
> The objective of the research and development program is to obtain an economical, highly reliable, and safe maritime plant that will be competitive with fossil-fueled propulsion plants. Under this program we expect to build a land-based test facility, a laboratory, in fact, where we can focus our development efforts, and design, build, and operate an advanced-type plant and identify, develop, and test future necessary improvements, particularly in comp-

ponents and layouts, for civilian maritime applications.
The other prong recognizes, of course, the indications by some of the industry that they are willing to proceed immediately, using primarily their own funds, with the construction of nuclear powered merchant ships. The AEC will be happy to cooperate with the Maritime Administration in its efforts to obtain firm fixed price proposals with reasonable guarantees from reactor manufacturers acceptable to prospective shipowners and the Maritime Administration.
We have had discussions with the Under Secretary of Commerce, Mr. Boyd, and representatives of the Maritime Administration on this approach, and we believe that this two-pronged approach will result in the most expedient development of advanced reactor systems that can meet the broad needs for economic trans-oceanic transportation. As you know, we are prepared to proceed with a modest effort now in accordance with the research and development program plan outlined to the committee previously this year." 22

The effort was indeed modest. Table VII shows funds requested and expended by the AEC for merchant ship reactors during the fiscal years following this program statement:

TABLE VII [23,40,41,42]

APPROPRIATIONS FOR MERCHANT SHIP REACTORS

	1966	1967	1968	1969
Requested:	$1,400,000	$500,000	$100,000	$100,000
Expended:	-675	49,066	*	*

*Not available at this time.

$8,643 of the 1967 funds were used to cover costs associated with shipment of waste fuel from the SAVANNAH prototype fuel element fabrication and irradiation program. The remainder of the 1967 funds were used for study and evaluation of nuclear fuel costs, capital costs, cost trends and maritime reactor design costs.[23] As noted, actual expenditures for fiscal years 1968 and 1969 are not yet officially available, but it is the author's understanding that these funds have not been expended.

Less than three years after Commissioner Ramey's description of the dual approach to a realistic program for the attainment of a competitive maritime nuclear power plant, the AEC virtually closed out their interest in merchant ship nuclear propulsion. George M. Kavanagh, Assistant General Manager for Reactors, in a statement before the Senate Subcommittee on Merchant Marine said:

"As you know neither of these approaches has been seriously undertaken by the Federal Government. There have been various reasons for this but a sufficient reason has been the lack of a clear indication that the goal - an economically self-sufficient ship system in a nuclear powered merchant fleet - was clearly attainable by either or by a combination of both. Developments in the reactor technology and industry in the last few years have actually tended to make the goal less clearly attainable than appeared likely some years previously." 6

Considering the outlay of funds for the merchant ship reactors program, one wonders how the goal became obscure in the interval between Commissioner Ramey's testimony and Mr. Kavanagh's statement.

In apparent substantiation for the last sentence of his statement, Mr. Kavanagh explained that the size of central station nuclear electrical generating plants has been steadily increasing, that they can compete more effectively in large sizes and that capital costs are less on a unit cost ($/KW) basis for large plants than for small plants. He further explained that maritime nuclear power plants are very small in comparison to those where economic nuclear electrical power is showing promise. He closed with the following statement:

"With this situation we are not now seriously promoting the long range development program using a land based test facility of the type we proposed for use several years ago. Similarly, the alternate evolutionary process contemplated in the bill (S.2650) before your committee does not appear to us to have the prospect of leading clearly to the type and degree of advance which would be needed to make nuclear propelled ships competitive with conventional ships."

"For the reasons described above we believe that a broad nuclear merchant ship program should not proceed at this time and that the Administration position in this regard is a reasonable one."

Mr. Kavanagh was correct in stating that the unit cost for large reactors is less than small ones; this has been borne out by capital cost studies of maritime applications as well as central station power plants.[25] He was also correct that reactors contemplated for installation in even the largest ships would be small in comparison to the presently evolving size of central station power reactors. But the conclusion that maritime nuclear power is uncompetitive by an analysis of capital cost trends in central station power plants is somewhat underwhelming and can hardly be considered a rigorous examination.

A straightforward translation of Mr. Kavanagh's final statement is that since the AEC is not proceeding with the research and development program outlined by Mr. Ramey, nor does it favor the near-term approach described by Mr. Ramey and supported by proposed legislation, the AEC is not supporting any merchant ship reactors program.

2. Nuclear Industry

Following significant success in the application of nuclear power to central station electric power plants, U.S. reactor manufacturers were considerably interested in the application of atomic energy to commercial marine use. The interest on the part of nuclear industry is readily understandable: ten to twenty reactors over a period of five to ten years plus follow-on support service represents large profit potential.

By 1965, the interest was still in evidence, but some of the vital signs had begun to falter. Testifying before the Joint Committee on Atomic Energy on the development of the atomic energy industry, Mr. John W. Simpson, Vice President of the Westinghouse Electric Corporation stated:

"We conclude that a technology to build merchant ship nuclear propulsion plants is available now. This technology is a direct spinoff from the Westinghouse commercial central station nuclear program, and thus will benefit from future development in that field. As has been the case for central station nuclear power plants, we are convinced that the best route to progress and cost reduction in the nuclear ship field is through the actual building and operating of power plants."

Mr. Simpson did not express any illusions about short term competition with oil fired ships. In response to a question from Chairman Holifield regarding the manner in which economical propulsion was to be achieved, he said:

"I think it is a question of hard work rather than real dramatic breakthroughs because I find it hard to predict a breakthrough. I don't think the problem is sufficiently far away from economic reality today that you would require a major advance. I think just hard work and the added volume of doing it many times. We have found in the central station reactors that by just building them and carrying on the development programs, the cost has come down very materially." 22

Mr. Simpson was representing that body of opinion that feels that the best road to competitive merchant ship nuclear power is not by research and development, but by volume production of maritime reactors now. This is the same as the second "near term" alternative described by Mr. Ramey. It is not surprising that this view would be that of a supplier. The difficulty in accepting this alternative is that it maximizes public risk. Volume production of maritime reactors without the benefit of a research and development program to select the optimum design that would best meet the unique needs of maritime application represents very significant outlays of federal monies without the assurances of R & D.

Other vendors were beginning to express dismay at the uncertain direction in the maritime reactors program. In comparing the West German maritime nuclear program with our own, Mr. Richard H. Harrison, Vice President of the Babcock and Wilcox Company was quite direct:

"Unfortunately, the maritime reactors program within our own country has charted a hesitant and confused course. In February of 1964, the AEC testified before this committee that it was terminating the maritime reactors program and that very little, if any, government support was required for the CNSG (B&W's maritime reactor) before commercial utilization. Actually, all AEC support for the CNSG had been terminated in August 1963, and since that time, we have continued on our own in furthering the development of

this reactor."

"We understand that the AEC is now planning a large-scale research and development program based on integral compact water reactor of which our CNSG is the first and foremost type - a type which last year was refused support because it was then considered by the AEC to be noncompetitive with an alternate nonwater concept. Assuredly, B&W cannot compete with the Government in developing this reactor, and we must reassess our own program when the character and scope of the reoriented AEC plan are made public. In the final analysis, if development of a commercial design is to be successful, the AEC and industry must reestablish a common basis for cooperation in keep-with the spirit and intent of the Atomic Energy Act of 1954." 22

In an effort to take the present pulse of the nuclear industry with respect to interest in maritime reactors, the author addressed a letter of inquiry to the five leaders in that field. Three of the five did not reply. The reply of Combustion Engineering said:

"While Combustion Engineering maintains interest in commercial nuclear ship propulsion, we do not presently have a nuclear steam supply system for merchant ship application in our product line. Development of our UNIMOD reactor, with which you are familiar, was discontinued about four years ago because of lack of commercial interest in the application. I might point out that the reactor for the German ore carrier 'OTTO HAHN' now undergoing testing employs the 'self pressurized' concept first introduced by Combustion." 26

Personal correspondence with individuals in the industry brought similar replies:

"I am most interested by your study. You should know, however, that all work terminated in mid 1965. I believe it was not toolong after that, that the other companies who had been pursuing this maritime program also terminated or severely cut back their efforts. I know of no work currently in this area other than your study.

Another reply:

"Because of the lack of a clear-cut maritime nuclear propulsion policy in Washington, the Company's nuclear merchant ship group here was dissolved a year or so ago and the personnel assigned to other tasks. Unfortunately, no one is available to provide specific answers to the questions raised by your letter."

Interest in the merchant ship reactors program on the part of the nuclear industry is clearly hibernated. The close coupling between industry's disinvestment of interest and the actions of the Atomic Energy Commission can hardly go unnoticed.

3. Shipowners

In May 1966, the Maritime Administration addressed a letter of inquiry to 56 shipping companies to determine shipowner interest in merchant ship nuclear power.

Nine percent, representing 15% of the polled companies' ships, indicated definite interest in near-term nuclear ships. Forty-five percent of the companies, owning 61% of the ships, were interested only if favorable economies could be proven. Forty-six percent, owning 23% of the ships were either not interested or did not reply. [27]

Testifying in support of Title X of the proposed amendment to the Merchant Marine Act of 1936 before the House Subcommittee on Merchant Marine in 1968, Admiral John M. Will, U.S. Navy (retired), Chairman of the Board of the American Export Isbrandtsen Lines, Incorporated (AEIL), made the following statement:

"Continued operation of NS SAVANNAH further convinced us not only of the feasibility of nuclear merchant ship operation, but that in the not too distant future such ships would have a rightful place in our merchant marine merely from the standpoint of economics.

Accordingly, in January 1966 we made a specific and detailed proposal to the Maritime Administration for the construction of three high-speed nuclear container ships for sailing on Trade Route 12."

"In the latter half of last year, as a result of price escalations announced by the industry, we did some work to update our construction proposal, and to review the economics of the matter. Our initial proposal was predicated on the belief that the three large, high-speed ships were going to be economically competitive with similar fossil-fuel fired ships.

Our position today is essentially unchanged from the standpoint of enthusiasm. We believe the potential is there but the road now appears to be a bit longer than we thought.

Admittedly, in light of the cost situation existing today, we as a private operator cannot assume the total burden of a nuclear ship program. However, if some considerations are given to details of the added costs of construction and operation, including those related to fuel

charges, we are both willing and much interested, as we have stated before, in undertaking such a program."

"In summary, I feel that SAVANNAH experience points only to success in the use of nuclear power in a merchant vessel. I believe that the economics for high-speed runs are loaded in favor of nuclear. I believe the time to build additional nuclear merchant ships is now." 5

The proposal referred to by Admiral Will involves the construction of three 70,000 SHP nuclear powered container ships on routes between the United States and the Far East at speeds of 30 knots. Total cost for the three ships ranges from $102 to $132 million dollars. AEIL agreed to provide some $30 million of the total construction cost of the three ships.[18] The Maritime Administration is unable to act on the proposal even if the funds were available for the purpose, since the Merchant Marine Act of 1936 limits the amount of construction differential subsidy to 55% for ships of the type proposed.

Since AEIL is the only shipowner in the United States with experience in the operation of nuclear powered merchant ships by virtue of their agency for the government in the operation of SAVANNAH, they probably represent the most progressive point of view among shipowners towards nuclear power.

The American Merchant Marine, propped as it is through the system of direct and indirect subsidies and struggling for survival in world competition, is in no position to underwrite the cost of merchant ship nuclear power.

C. Summary

It can be stated with little equivocation that the state of merchant ship nuclear power is represented by a complex muddle of conflicting positions and complete stagnation.

PART III.
THE ECONOMIC FEASIBILITY OF MERCHANT SHIP NUCLEAR POWER

A. Preface

Having completed the tasks of reviewing the origins and effect of present day maritime law, the state of the United States Merchant Marine and the positions of those forces that control merchant ship nuclear potential, this study will now present its dominant purpose: the economic feasibility of nuclear propulsion for commercial marine application.

B. Concept

As in most feasibility studies, this paper will examine two alternatives: the conventional oil fueled ship as the defender and the nuclear powered ship as the challenger. These competing alternatives will be compared in a realistic manner. The basic concept of this comparison is that the best index of engineering success is profitability and the only meaningful measure of profit is the after-tax return on investment. Although there has been a serious effort to reflect actual costs in 1970 dollars, no claim can be made for cost precision. The dominant purpose of the study is to compare the relative profitability of the two alternatives; therefore, as long as correct relative costs are presented, the results will be qualitatively correct if not quantitatively precise.

Secondly, the reader will not find in this study the phrase too often contained in similar comparisons: "The nuclear powered alternative is cost competitive at speeds of ___ knots and above." Such statements have little meaning if the shipowner can build a slower ship that offers cheaper transportation. In short, the defender will be met on its own ground.

C. Approach

The construction of a mathematical model of a hypothetical, yet realistically configured contemporary merchant ship will be described. All cost factors related

to the construction and operation of the ship are contained in the model. The model is then "put to sea" in both a conventional and nuclear configuration under identical conditions and the results of operations are economically compared. All model operations are accomplished through the medium of an IBM 360 model 50 computer.

The study compares nuclear and fossil fuel power by assessing the relative costs and profitabilities without government support or subsidy. In the opinion of the author, these would only serve to clutter the search for true economic viability. As a practical matter, the type ship under study is not eligible for either the construction or operating differential subsidy.

D. Ship Description

The ship under study is a bulk-cargo, representative of ore carriers, grain ships, etc. and is designed for a round trip sailing of 24,000 nautical miles. The ship is assumed to sail with full cargo deadweight in one direction and return in ballast. The cargo discharge point is east coast United States. The ship is part of a captive fleet, corporation owned and equity financed. Owners require a return on investment of 10% after taxes of 48%. Ship life is assumed to be 25 years.

A bulk-cargo was selected for this study for the following reasons:

1. In terms of tonnage, 72% of our dry-cargo trade is bulk, while only 28% is liner.[5]
2. Serious literature on comparative ship economics recognizes the bulk-cargo type as having the greatest potential for nuclear power application.[1,2,28,29]
3. It is easier for the reader to see how the fuel weight saving potential of nuclear power is exploited as compared to other type ships. In the bulk-cargo, the space normally occupied by oil fuel is converted directly to increased cargo in the nuclear alternative.

The technical characteristics of the ship under study are listed in Table VIII on the following page.

TABLE VIII

TECHNICAL CHARACTERISTICS

Length between perpendiculars (L)	735.0 feet
Limiting operating draft	34.0 feet
Design draft	37.5 feet
Depth (D)	52.5 feet
Beam (B)	93.75 feet
Block coefficient at design draft	0.80
Beam-draft ratio at design draft	2.5
Length-draft ratio at design draft	19.6
Length-depth ratio	14.0
Displacement at design draft	59,100 long tons
Displacement at operating draft	53,500 long tons
Machinery	Single screw, steam turbine
Shaft horsepower	To be optimized
Speed	To be optimized

E. Model Construction

Construction of the model is described in five sections: Construction Costs, Annual Operating Costs, Annual Transport Capacity, Capital Recovery Factor and Measure of Merit. Cost levels are appropriate only for a single ship acquisition in United States shipyards.

1. Construction Cost

Construction costs consist of hull structure, outfitting and hull engineering, machinery, miscellaneous and design. The basic approach will be to show the computational method for material and labor associated with these cost centers. Profit, overhead, labor rates and inflation factors will be summarized at the end of this section.

a. Hull Structure

Hull structure includes the main hull structure, superstructure, deck houses, all internal divisional bulkheads, masts, kingposts and foundations. The hull structure is assumed to contain only a nominal amount of special steels and aluminum alloys. One long ton (LT) = 2240 pounds. Structure cost is computed as follows:

Material = ($220/LT) * structure weight (LT)

Labor = (61.5 man-hours/LT) * structure weight (LT)

Structure weight = 0.32 * cubic number

where: 0.32 = the structure steel weight coefficient

cubic number = (L*B*D)/100

Structure weight of the nuclear ship is increased by 100 tons[30] to provide for a collision barrier. The collision barrier serves to absorb the deformation strain in the reactor area in the event of collision in order to prevent destructive forces from breaching the reactor containment.

b. Outfitting and Hull Engineering

Outfittings costs include hull insulation, joiner bulkheads, hawse pipes, deck fittings, cargo booms, anchors, rudder and stock, galley equipment and hatch covers. Hull engineering consists of non-propulsion mechanical equipment such as deck machinery, steering engine, generators, ventilation and air conditioning systems, refrigeration plants, hull piping systems, pumps and electrical systems. The ship is assumed to be non-self-loading and equipped with mechanical hatch covers. Costs are computed as follows:

Material = ($1,575/LT) * O&HE weight (LT)

Labor = (260 man-hours/LT) * O&HE weight (LT)

O&HE weight = 0.052 * Cubic number

where 0.052 = the O&HE weight coefficient

c. Machinery

Machinery costs include all propulsion equipments, fittings, piping systems, instruments and controls from screw to stack. It is a critical element in this study and will be approached accordingly. Assumptions are as follows:

(1) The Nuclear Steam Supply System (NSSS) incorporates an air-cooled reactor such as described in references 20 and 30.

(2) Development cost for the NSSS has already been absorbed. This is a fact for several maritime reactor systems[24] including the air-cooled reactor (ACR) described in reference 20 - the General Electric 630A.

(3) Total machinery cost is reduced by 9% for machinery arrangement aft as in this case.

(4) The engineering plant is non-automated.

The total installed cost of the conventional machinery plant, including profit and overhead is estimated as follows:

$$\text{Cost} = 0.91 * \$647{,}000 * (\text{SHP}/1000)^{0.6}$$

where 0.91 = machinery aft reduction

SHP = shaft horsepower

The total installed cost of the nuclear machinery plant, including profit and overhead but exclusive of the cost of the NSSS is estimated as follows:

$$\text{Cost} = 0.91 * \$635{,}000 * (\text{SHP}/1000)^{0.6}$$

The cost of the ACR Nuclear Steam Supply System is estimated as follows:

$$\text{NSSS Cost} = \$925{,}000 * (\text{SHP}/1000)^{0.4}$$

The capital cost attributed to the General Electric Model 630A ACR for units after a market had been established was estimated to be $1,900,000.00 in 1965.[30] In an attempt to arrive at first-cost estimate and make approriate allowance for the substantial increases in NSSS costs in recent years, the NSSS cost formula above represents an increase of approximately 80% over the 630A price.

d. Miscellaneous

Miscellaneous hardware costs include such elements as engineering, staging, cleaning, launching, temporary lights, trial expenses, material handling and so forth. These costs are estimated in the model by increasing the sum of all material costs by 5% and labor by 15%

Miscellaneous software costs that must be added to the construction bill are administration and technical services, plan approval, inspection, legal fees, consulting fees, naval architects' fees, transportation and communications. Software costs are estimated as follows:

$$\text{Cost} = \$350{,}000 + 0.015 * \text{Total Construction Cost}$$

e. Design

The shipbuilder's design charges are expressed as a percentage of the total of structure cost, outfitting and hull engineering, machinery and miscellaneous hardware. For the conventional ship, this is estimated to be approximately 4%. For the nuclear ship, the estimate is 9%.[27] A significant contribution to the difference is the inclusion of a very conservative figure for the shipbuilder's

reactor plant first-time design and engineering charges. This cost could vary significantly depending on whether the shipbuilder had prior nuclear ship construction experience and facilities.[25]

f. Overhead, Labor Rate, Profit and Inflation Factors

The model applies overhead, labor rate, profit and an adjustment for cost inflation to each of the construction costs centers. Overhead has been approximated as a percentage of direct labor. This percentage will vary widely among shipyards and is dependent on such factors as shipbuilding volume and economic climate. A figure of 70% has been incorporated into the model. Profit is expressed as a percentage mark-up on the total of material, labor and overhead and is set at 5% in the model. The average labor rate, representing the full range of skilled and unskilled labor needed to build the ship is taken as $3.50 per hour. Finally, to each of the construction costs has been added an appropriate inflation factor in order to arrive at 1970 dollars.

These factors are at best rough approximations, but so long as they are applied equally to both the conventional and nuclear alternatives, the qualitative results will not be effected.

2. Annual Operating Costs

Annual Operating Costs include Wages, Subsistance, Maintenance and Repair, Stores and Supplies, Insurance, Overhead and Miscellaneous, Port Expenses, Fuel Costs and Depreciation. There is a great variety of approaches to the subject of operating costs and each is only educated approximation. There is no particular virtue claimed for the methods used in this study, except that the results seem to agree fairly well with others.

a. Wages

Wages include the pay of officers and crew including regular wages, overtime, vacation pay, emergency allowances and bonuses. Contributions to welfare and pension

plans as well as unemployment compensation and similar social security taxes would also be included under this heading.[29] This cost is directly dependent on the number of personnel in the ship's complement. It is assumed that the nuclear ship will require no more personnel than the conventional alternative. Total complement is calculated as follows:

$$\text{Complement} = 1.25\left(13(CN/1000)^{1/6} + 12(SHP/1000)^{1/5} - 12 \right)$$

where: 1.25 = coefficient for stewards

13 = coefficient for deck

CN = cubic number

12 = coefficient for engineering

The number 12 is subtracted from the total since this formula is applicable to cargo-liners and bulk carriers have a complement of about a dozen less.

It is assumed that the average wage for the conventional ship is $15,000 per man per year. For the nuclear ship, it is assumed that these wages will be increased by 10% due to the increased level of skills and education required for personnel in the engineering and command structure.[29,31]

b. Subsistance

Subsistance includes all edibles for consumption by the ship's complement and board and room allowances in lieu of subsistance and lodging aboard ship.[29] Annual subsistance cost is computed by multiplying the complement by $770. This figure is the same for both nuclear and conventional crews; nuclear personnel are better paid, not necessarily better fed.

c. Maintenance and Repair

Maintenance and Repair includes a wide range of charges including cleaning, painting, scraping, inspection, cost of preventive maintenance to ship equipments, repairs and spare parts. M&R costs are hardly susceptible to definitization; trade route weather, owner's standards and other

factors create wide variation. This cost is estimated as follows:

$$M\&R = \$10{,}000(CN/1000)^{2/3} + \$4{,}500(SHP/1000)^{2/3} + \$40{,}000$$

The first factor in the equation represents the annual cost of maintenance and repairs to the hull, the second factor is machinery M&R and the $40,000 is a correction for bulk carriers.

There is a credible argument for lower nuclear M&R costs because of the superior reliability of equipment demanded by AEC licensing standards.[20] There is an equally creditable argument that although nuclear repairs are less frequent, they are more costly when needed. In the absence of experience, they are placed equal in the model.[26,29,32]

d. Stores and Supplies

Stores and Supplies include all consumables and expendible equipment such as tools, utensils, paint, cleaning materials, lubricating oil and so forth. Most of these are associated with crew-performed maintenance; therefore, the annual cost of stores and supplies is a function of crew complement:

$$\text{Cost} = \$80(\text{complement}/10)^4$$

This cost is considered to be equal for the two alternatives.

e. Insurance

The annual cost of insurance includes coverage for Protection and Indemnity, Hull and Machinery and War-Risk. Protection and Indemnity (P&I) protects the shipowner against liability lawsuits. This study assumes that such action would be the result of crew action and therefore is a function of complement:

$$P\&I\ \text{Cost} = \$965(\text{complement})$$

P&I rates are set 50% higher for the nuclear ship than the conventional. The potential release of fission products to the atmosphere and resultant biological damage is the basis for this assumption.

Hull and Machinery (H&M) insurance provides protection against damages to or the loss of the ship and is a function of the owner's past record. An average cost is assumed in the model:

H&M Cost = $10,000 + 0.007(construction cost)

War-risk insurance is estimated to be 0.1 percent of the construction cost for both the conventional and nuclear ships.

f. Overhead and Miscellaneous

Overhead and Miscelleous (O&M) costs include fleet management expenses, communication, crew transportation, survey fees, bills of health, fresh water and so forth. This cost is the same for both alternatives and is estimated on the basis of vessel displacement:

O&M Cost = $50,000 + $12(displacement/1000)

g. Port Expenses

Port expenses include such costs as pilotage, customs fees, tonnage taxes, tug services, line handlers and so forth. Since a specific trade route has not been specified for this study other than a round trip distance of 24,000 miles, this cost can only be generalized on the basis of displacement:

Port Costs = ($1,000 + $80(displacement/1000)) * RT

where: RT = the number of round trips per year

The computation for RT will be described in Section 3: Transport Capacity.

As was the case for maintenance and repair, there are conflicting viewpoints on whether port charges would be the same for both alternatives. The nuclear ship will experience costs that are unique to the nuclear technology: health physics support and radioactive waste disposal. On the other hand, the nuclear ship will not bear the constant costs associated with port refueling which are not insignificant on an annual basis. For these offsetting reasons,

no charges are included in the model for the unique port charges of the nuclear ship nor are any included for bunkering fees or oil barging for the conventional.

It should be noted that no canal passage has been assumed either in this section nor in the section on transport capacity. This is mostly for the convenience of the author but the now existing conditions in the middle east provide a convenient rationale.

h. Depreciation

Non-subsidized ships are permitted to use any reasonable method of depreciation as long as it is consistantly applied. The methods generally used are straight-line, declining balance and sum of the years-digits. For subsidized vessels, any of these three methods are acceptable for income tax purposes, but for the purpose of subsidy accounting, owners must depreciate on the straight-line basis.[6]

The model depreciation is on a straight-line basis and assumes no salvage value at the end of ship life:

Depreciation Cost = construction cost/25

i. Fuel

Computation of fuel costs are complex and critical to the purposes of this study. Accordingly, they shall be described in some detail.

(1) Conventional Ship

To find total annual fuel cost, the following equation must be solved:

Annual fuel cost =

barrels/sea day * \$/barrel * sea days/RT * RT/year = \$/year

Each of the factors of this equation shall be described in turn. The conventional bulk-cargo ship is assumed to burn bunker "c" oil at the following rate:

Barrels per sea day = 50 + 34.2(SHP/1000)

For reasons that will be explained in the section on transport capacity, the conventional ship is assumed to take on bunkers at the point of cargo discharge - east coast U.S. Through the courtesy of the United States Coast Guard, the author obtained the cost of bunker "c" at each of five major ports on the eastern seaboard. As of 13 January 1969, the average price of oil fuel at these ports was $2.15 per barrel, exclusive of barging costs.

The third factor in the equation, sea days per round trip, is calculated as follows:

$$\frac{(\text{nautical miles/RT})}{(24\text{ hours/sea day}) * (\text{speed in nautical miles/hour})}$$

or:

(24000)/(24*speed)

The computation for speed will be described in the section on transport capacity, as will the final factor in the equation, round trips per year.

Collecting all factors, the total annual fuel cost for the conventional ship can be expressed:

Cost = (50+34.2*(SHP/1000))*(2.15)*(24000/(24*speed))*RT

(2) <u>Nuclear Ship</u>

Before formulating the equation for nuclear fuel cost used in the model, some background is necessary to understand the basic dependences of nuclear fuel cost and the variables involved. Nuclear fuel cost can be thought of as consisting of the following factors:[33]

(a) Cost of Preparing Uranium

The cost of uranium preparation for installation in the reactor core includes the costs of natural uranium, conversion to UF_6, enrichment in U^{235}, conversion of enriched UF_6 into UO_2 and the fabrication of the UO_2 into fuel elements.

(b) Cost of Fissionable Material

The net cost of the fissionable material burned in the core is based on the reduction in U^{235} less credit obtained from the production of plutonium.

(c) Cost of Recovering Residual Fuel Value

The cost of recovering the residual value of uranium and plutonium remaining in the spent core includes the cost of shipping the spent fuel and the chemical processing necessary to restore the fuel to marketable form.

(d) Interest on Working Capital

Each step in the fuel cycle, whether before, during or after irradiation of the fuel in the reactor represents a requirement for working capital. The cost of the working capital is the interest expense on these funds.

The importance of interest rate to the competitive position of the nuclear ship cannot be overemphasized. The dependency of interest rate and the cost of fuel is approximately 0.1 mills/SHPHR for every 1% change in the interest rate. At the present time, a changeover from government to private ownership of nuclear fuel is in process. Prior to this change, the AEC had charged an interest rate or "use charge" of 5.5% per year on the cost of the reactor fuel load. If private ownerships adjusts this rate, the cost of nuclear fuel will change accordingly.

Utilization, or the rate at which the fuel is used in the ship, is second only to interest rate in importance to the economics of nuclear fuel. The less time the ship is at sea, the longer it will take to expend the fuel. The longer the fuel is on board, the higher the interest expense will be. Part IV of this study will demonstrate graphically the importance of this concept.

Nuclear fuel costs are expected to decrease with time through improvements in technology such as improved fuel burnup properties, reduction in the the costs of enrichment and the economies of volume in the fuel cycle processes. It is important to understand that the volume economy will depend to a considerable extent on the degree of similarity between maritime reactor fuel design and the present majority user of nuclear energy, the central station power plant. The greater the similarity, the greater the economy in fabrication and reprocessing.

The nuclear fuel rates incorporated into the model are a linear adaptation of the rates cited for the General Electric 630A Mark IV, a nuclear fueled steam generator-superheater designed for merchant ship application. Information on the 630A is taken from reference 20 and cited herein with the kind permission of Mr. E.B. Delson of General Electric who co-authored the reference with Mr. E.C. Hunt. A portion of the fuel cost curves which appear in the reference are shown in Figure 1.

The assumptions appearing in the reference in support of these rates are as follows:

1. The price of natural uranium will be $5 per pound by 1971.
2. The presently established price for enrichment will continue through 1971, then with toll enrichment and private ownership of fuel, will be gradually reduced to 70% of present cost by 1974. (Toll enrichment is an AEC service which provides for the enrichment of privately owned uranium for a fee based on the amount of separative work required. The service is scheduled to begin in 1969 and was authorized under the Private Ownership of Special Nuclear Materials Act of 1964. It is expected to be extensively used in the production of enriched fuel for nuclear reactors.[34])
3. The cost of reprocessing and turnabout will be $24,000 per day from 1970 to 1972, then reduce to about $18,000 per day by about 1977 and then hold constant. (Turnabout is the process in which the reprocessing facility is cleaned and prepared for the reprocessing of other types of fuel. This relates to the previous comment that nuclear fuel economy will be dependent on similarity of fuel with other types.)
4. The use charge will remain steady at 5.5 % from 1971 on.

To the extent that these conditions do not obtain at the time of this writing, fuel costs are subject to appropriate adjustment.

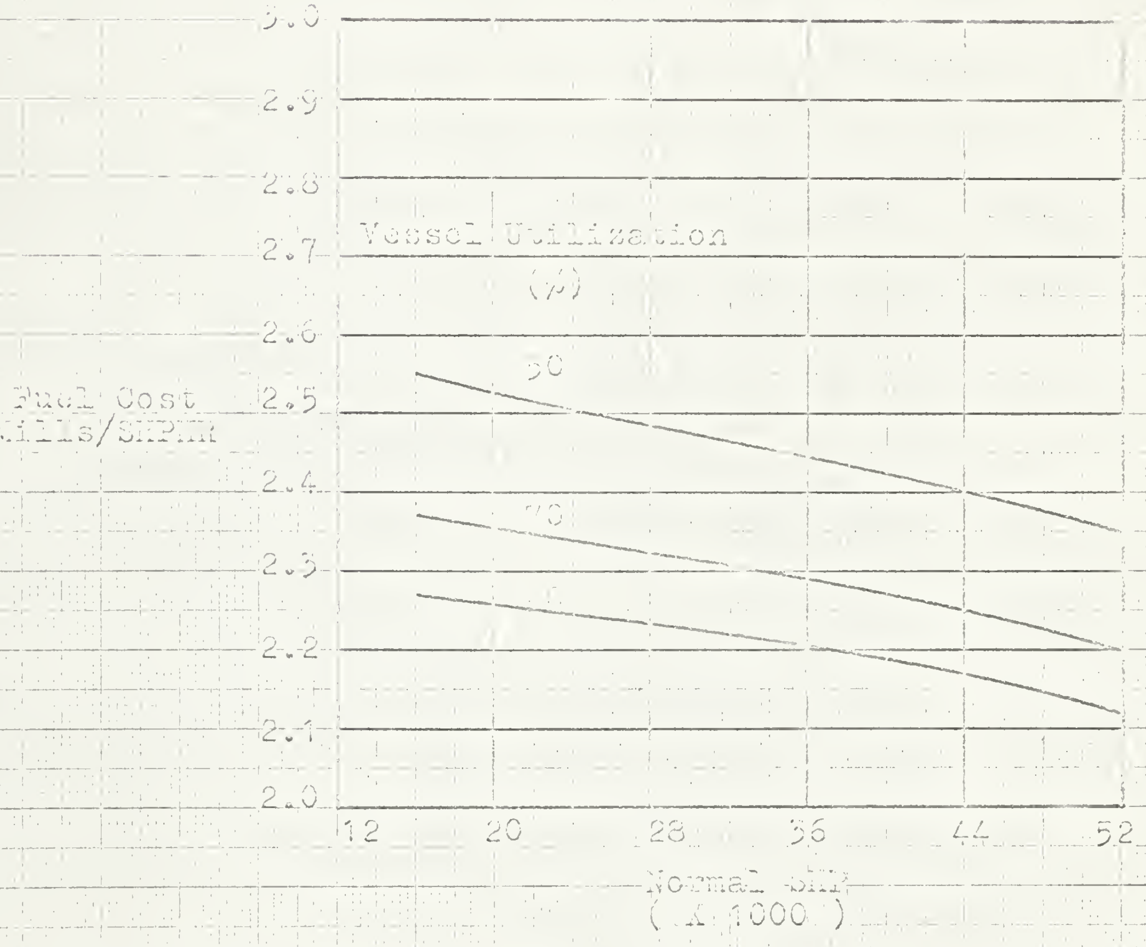


FIGURE 1: 630A FUEL COSTS

(25-year average for period starting 1968)

As a matter of interest, while the 1965 quoted price for the production model 630A was significantly lower than comparable pressurized water reactor concepts for maritime propulsion, the 630A nuclear fuel costs were higher. It is also interesting to note that while the highest fuel rate that appears in figure 1 is about 2.55 mills/SHPHR, the oil fuel price of $2.15 assumed in the model equates to about 3.5 mills/SHPHR. The significance of this difference to the competitive position of the two alternatives will be more apparent in part IV of the study.

With some background for the fundamental elements of nuclear fuel cost established, the specific formula for annual nuclear fuel cost used in the model can now be set forth:

Annual Fuel Cost =

Rate * SHP * hours/seaday * seadays/RT * RT/year * $/mill

= $/year

where: Rate = mills/SHPHR

or:

Cost = Rate * 24 * 24000/(24 * speed) * RT/1000

simplifying:

Annual Fuel Cost = Rate * SHP * 24/speed * RT

3. Annual Transport Capacity

The annual transport capacity is defined as the number of long tons of cargo carried per year and is of course the source of revenue. The annual transport capacity is obtained by multiplying the long tons of cargo carried per round trip by the number of round trips per year (RT). Round trips per year is calculated as follows:

RT = (365 days/year * U)/(seadays/RT + portdays/RT)

Each of the terms in this equation will now be defined and formulated:

a. Utilization

Utilization (U) is the percentage of days in a 365 day year during which the ship is either at sea in transit between the cargo loading and discharge ports, or is in these ports for the purpose of loading or discharging cargo. The difference between 365 days and the number of days involved in this activity is the number of days that the ship is in a repair and upkeep status or is idle because of a lack of cargo charter.

b. Seadays per Round Trip

Seadays per round trip is the in transit status defined above and is computed as follows:

Seadays/RT = round trip distance/(24 * speed)

c. Speed

Speed is extracted from an approximation of the following conventional formula:

$$EHP = (V/350)(\tfrac{1}{2}dAV^2C_t)$$

where: EHP = effective horsepower

V = velocity, ft/sec

d = density of water, slugs/ft^3

A = total wetted surface, ft^2

C_t = total resistance coefficient

This formula is corrected for appendages to the hull such as bilge keels, then divided by the propulsive coefficient appropriate to the characteristics of the ship under study to yield SHP. In the model, SHP is the entering argument and velocity is solved for in nautical miles per hour.

d. Portdays per Round Trip

Portdays per round trip is as defined above under utilization and is estimated as follows:

Portdays/RT = cargo deadweight/22000 + 2

For the purposes of this study, an average figure of 3.6 portdays per round trip has been taken.

Having calculated round trips per year, it remains to compute cargo carried per round trip in order to multiply the two to obtain annual transport capacity. The ship's cargo capacity is obtained as follows:

DISPLACEMENT
− LIGHT SHIP
= DEADWEIGHT
− FUELWEIGHT
− MISCWEIGHT
= CARGO CAPACITY

Each of these factors will now be defined and formulated.

e. Displacement

Displacement is the weight of the volume of water displaced by the floating ship and has been established in Table VIII as 53,500 long tons.

f. Lightship

The lightship condition is the sum of the weights of structure, outfit, hull engineering and machinery. The first three of these have been formulated in the section on construction costs. Machinery weight is estimated as follows:

$$\text{Machinery Weight} = 214(\text{SHP}/1000)^{\frac{1}{2}}$$

Although nuclear machinery plants may someday be equal to or less in weight than the conventional plant, such is not the case today. In the model, the nuclear machinery plant is estimated to weight 5% more than the conventional.[26,30]

g. Deadweight

As defined in the formula above, deadweight is the difference between displacement and the weight of the fixed structures of the ship. It is the weight of the volume of the ship remaining for cargo, fuel and miscellaneous consumables necessary to operate the ship.

h. Fuelweight

Fuelweight is a critical element of this analysis. For the conventional ship, the amount and therefore weight of fuel required is a function of voyage distance and ship speed. The greater the amount of fuel required, the less volume remains for revenue-producing cargo. Nuclear fuel weight is independent of both speed and distance and varies only with the power rating of the reactor. Nuclear fuel weight is therefore a constant and its insignificant weight is combined with the weight of the nuclear machinery plant as part of lightship weight. Since the cargo capacity in the nuclear ship is not decreased by additional fuel oil requirements, it has a significant advantage over the conventional, particularly where long trade routes and high speeds are concerned. As will be seen in part IV, this and fuel cost are two important advantages in nuclear ship economics.

For the conventional ship, fuelweight is calculated as follows:

Fuel Weight = barrels/seaday * seadays/RT * long tons/barrel

or:

Fuel Weight =

$$1.15 * 0.5 * (50 + 34.2 * SHP/1000) * \frac{RT\ distance}{24 * speed} * 1/6.62$$

where:

1.15 = a safety margin allowance of 15%

0.5 = half bunkers: in order to reduce the effect of fuel deadweight on cargo capacity, the ship is assumed to take on bunkers at the cargo discharge port

6.62 = the number of barrels per long ton

Additional economies might be achieved for the conventional ship by taking on half bunkers at both ends of the voyage if the price of bunker "c" is cheaper at the loading port than it is on the east coast of the U.S.

Nuclear fuel weight is combined with nuclear machinery plant weight as explained above and for the ship under study,

would be negligible at something less than 200 kilograms (440 pounds).

i. Miscellaneous Deadweight

Miscellaneous deadweight includes such items as lubricating oil, crew, crew effects, provisions, stores, feed and domestic water. This weight is small and is generally under 300 tons. In the model, miscellaneous deadweight is assumed to increase by 2 tons per thousand SHP increase.

The cargo capacity per round trip thus arrived at can now be multiplied by the number of round trips per year to obtain cargo capacity per year or annual transport capacity.

4. Capital Recovery Factor

Capital Recovery Factor (CRF) is that percentage of the total construction cost of the ship that must be returned annually to the owners to pay operating costs and taxes, and still provide a yield of 10% after taxes. Capital recovery factor is defined as follows:

$$CRF(\text{before taxes}) = A/P$$

where: A = annual return or revenue less operating costs before taxes

P = total construction cost

$$CRF'(\text{after taxes}) = A'/P$$

where: A' = annual return after tax

CRF' is developed as follows:

$A' = A - t(A - P/N)$, where t = tax rate and N = ship life and P/N = depreciation.

or:

$$A' = A - tA + tP/N$$

so:

$$A' = A(1 - t) + tP/N$$

Dividing both sides by P:

$$A'/P = A/P * (1 - t) + t/N$$

therefore:

$$CRF' = CRF(1 - t) + t/N$$

inverting:

$$CRF = \frac{CRF' - t/N}{1 - t}$$

Since the assumptions for the model are a tax rate of 48%, ship life of 25 years and after tax yield of 10%:

$$CRF = \frac{0.1102^{*} - 0.48/25}{1 - 0.48} = 0.1750$$

*Obtained from Capital Recovery Tables for 10% yield and 25 periods.

A graphic presentation of the division of revenues is shown in Figure 2:

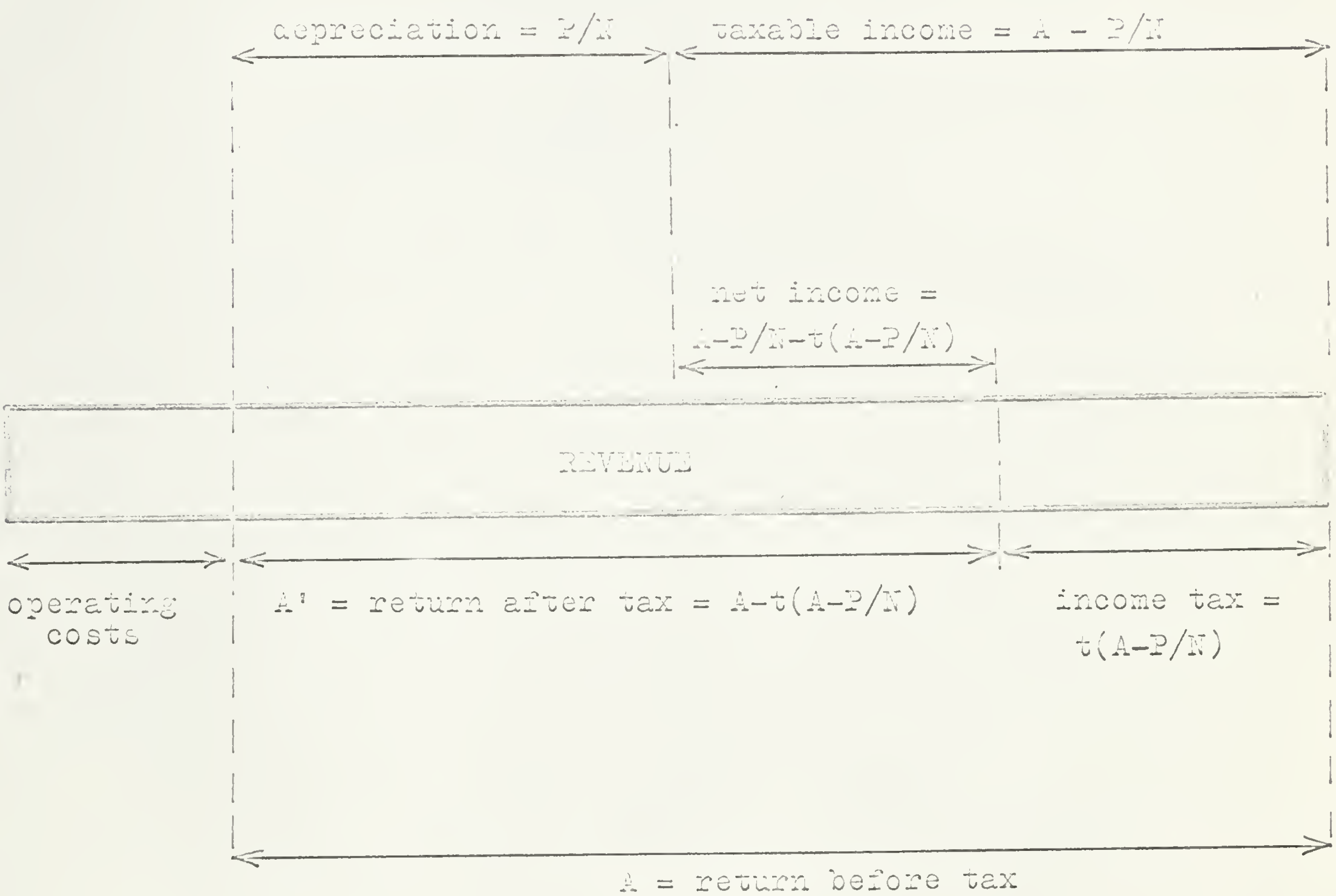


FIGURE 2: DIVISION OF REVENUE

5. Measure of Merit

Having established the procedures for computing construction costs, annual operating costs, annual transport capacity and capital recovery factor, the last and most important task is to describe the method by which the defender and challenger are to be compared economically. Since we have not specified what cargo is to be carried or at what port it is to be loaded, the revenues are unknown. Furthermore, these revenues will vary between the two alternatives because of difference in the annual transport capacity. An appropriate measure of merit under these circumstances is the Required Freight Rate (RFR). This is the cost in dollars per long ton that the owner must charge the customer in order to achieve the specified rate of return. Required freight rate is defined as follows:

$$\text{RFR} = \frac{\text{annual operating cost + capital recovery cost}}{\text{annual transport capacity}}$$

This measure is simple and effective. The alternative offering the lowest RFR is the better economic venture.

This completes the description of the model. A copy of the computer program constructed to accomplish the computations described is included as Appendix B. Appendix C is an example of the computer results of operations.

PART IV.

RESULTS OF OPERATION

A. Preface

This part presents the results of operating the model described in Part III over a ship utilization range of 70 to 95% and a power range of 5,000 to 50,000 shaft horsepower. Bulk-cargo ships are expected to be operational about 340-345 days per year. This norm is represented by a ship utilization of 95%.

B. Construction Cost

The construction cost of the two alternatives is presented in Figure 3. The cost of the nuclear ship is significantly higher than the conventional over the full range of power investigated. Construction cost in independent of utilization. (The shipbuilder doesn't care whether the owners use the ship or not as long as the builder is paid.) The construction cost of the nuclear ship is higher than the conventional because of the following factors:

1. Structure Cost

Nuclear structure cost is higher because of the necessity to include a collision barrier.

2. Machinery Cost

Nuclear machinery cost is far and away the most significant reason for the difference in construction costs. The intrinsic expense associated with the sophistication, required reliability and mandatory safety factors of nuclear technology causes the cost of the nuclear machinery plant to be virtually double that of the conventional oil fired boiler machinery plant.

3. Miscellaneous Cost

Miscellaneous costs are higher for the nuclear ship since they are expressed as a percentage of the materials and labor for structure, outfit, hull engineering and machinery.

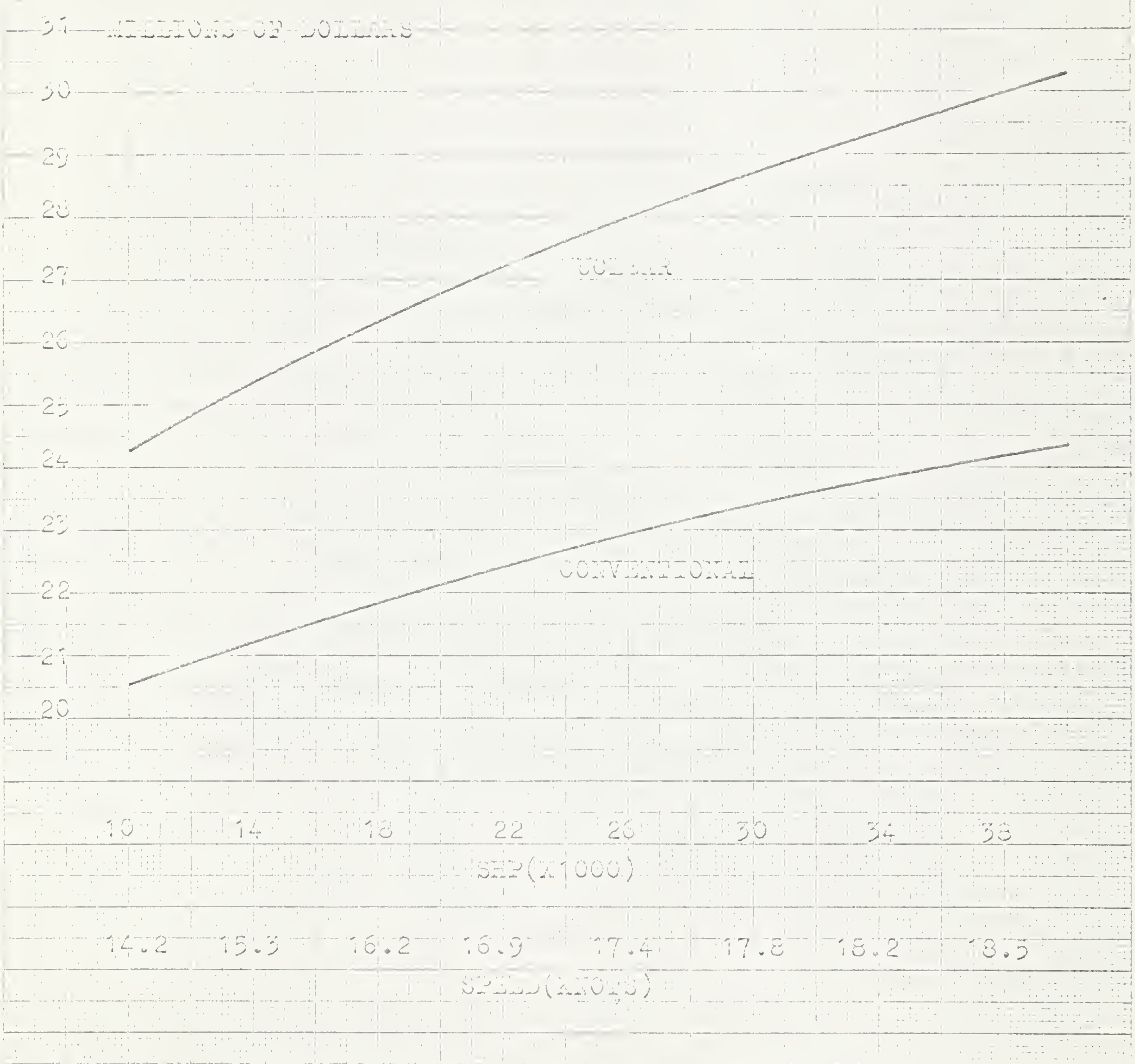


FIGURE 5: COMPARATIVE CONSTRUCTION COSTS

4. Design Cost

Design cost is higher since it is a percentage of the total construction cost and includes the shipbuilder's first time costs for installation of the nuclear machinery plant.

A breakdown of construction costs for the two ships is presented in Table IX below. Like subsequent tables in this part, the information is extracted from that part of the computer run-out representing a ship utilization of 95% and a power of 14000 SHP. As will be seen in the section on measure of merit, the required freight rate is lowest under these conditions.

TABLE IX

CONSTRUCTION COSTS

	Conventional	Nuclear
Structure	$7,763,572	$7,830,637
Outfit & Hull Engineering	6,912,674	6,912,674
Machinery	3,183,794	5,782,976
Miscellaneous	2,366,653	2,611,812
Design	979,141	2,245,133
Totals	$21,205,840	$25,383,232

C. Annual Operating Costs

Comparative annual operating costs are presented in Figure 4. This cost is higher for the nuclear ship except at extremely high powers beyond economic consideration. The causes for the higher nuclear cost are wages, insurance and depreciation. The single cost advantage of the nuclear ship in the operating cost catagory is fuel. As power is increased, the cost of oil fuel outruns the nuclear costs. This accounts for the convergence and eventual cross-over of the two curves. Comparative annual fuel costs are presented in Figure 5.

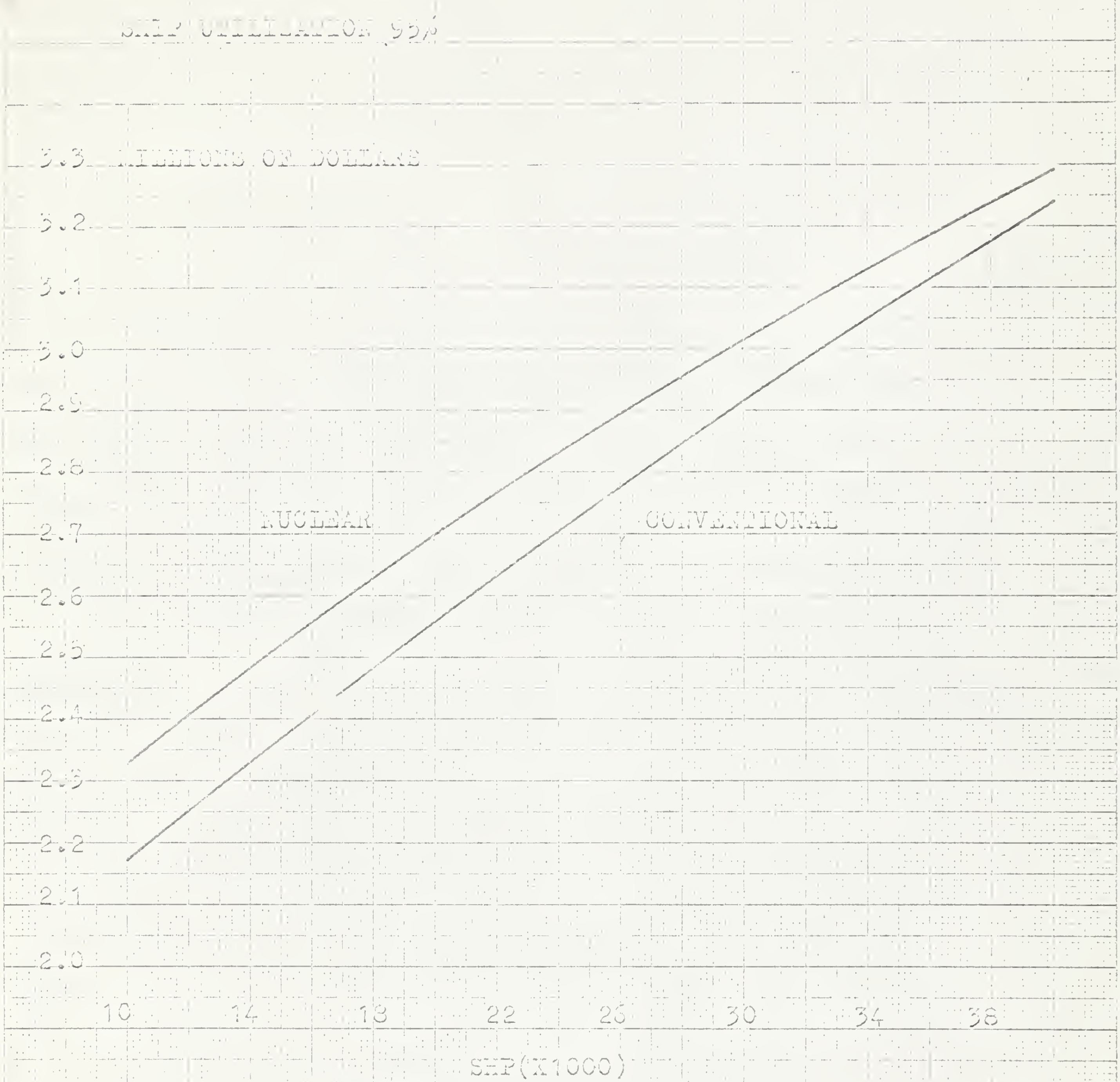


FIGURE 4: COMPARATIVE ANNUAL OPERATING COSTS

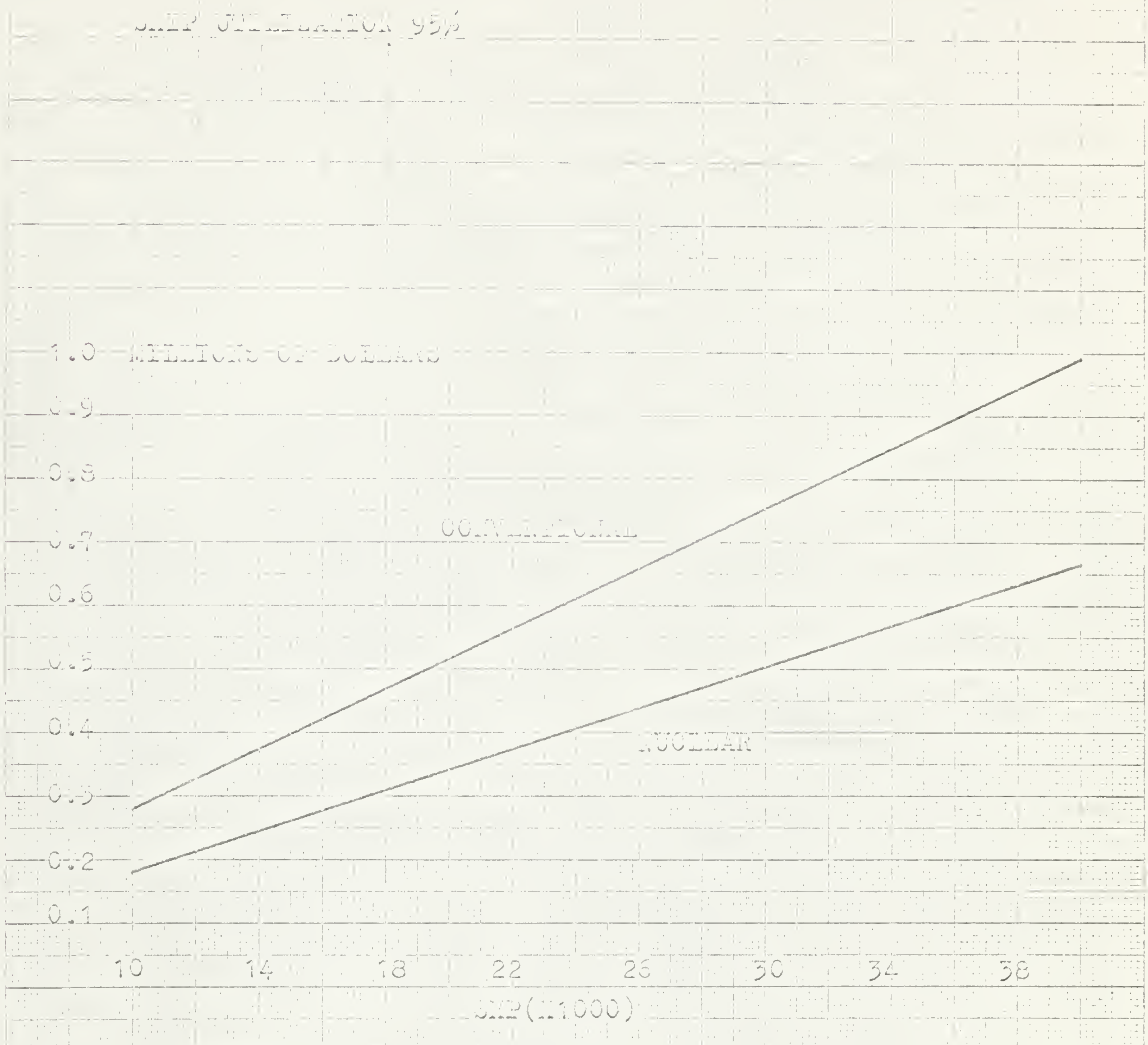


FIGURE 5: COMPARATIVE ANNUAL FUEL COSTS

A breakdown of annual operating costs for the two ships is presented in Table X below.

TABLE X

ANNUAL OPERATING COST

	Conventional	Nuclear
Wages	$585,000	643,500
Subsistance	30,030	30,030
Maintenance & Repair	177,068	177,068
Stores & Supplies	18,507	18,507
Total Insurance	217,260	269,517
Overhead & Miscellaneous	50,642	50,642
Port Expenses	26,613	26,613
Fuel	373,596	246,658
Depreciation	848,253	1,015,329
Totals	$2,326,969	$2,477,864

D. <u>Annual Transport Capacity</u>

Comparative annual transport capacities are presented in Figure 6 and show a decided advantage for the nuclear alternative. For reasons explained in Part III, the cargo capacity of the nuclear ship is unaffected by fuel weight considerations; consequently, as power is increased the cargo advantage of the nuclear ship increases dramatically. It is interesting to note that at power ratings in excess of 32000 SHP, the amount of oil fuel the conventional ship is required to carry is so great that annual transport capacity actually declines. This has very important connotations with respect to the characteristics of the ship that is the optimum candidate for nuclear propulsion.

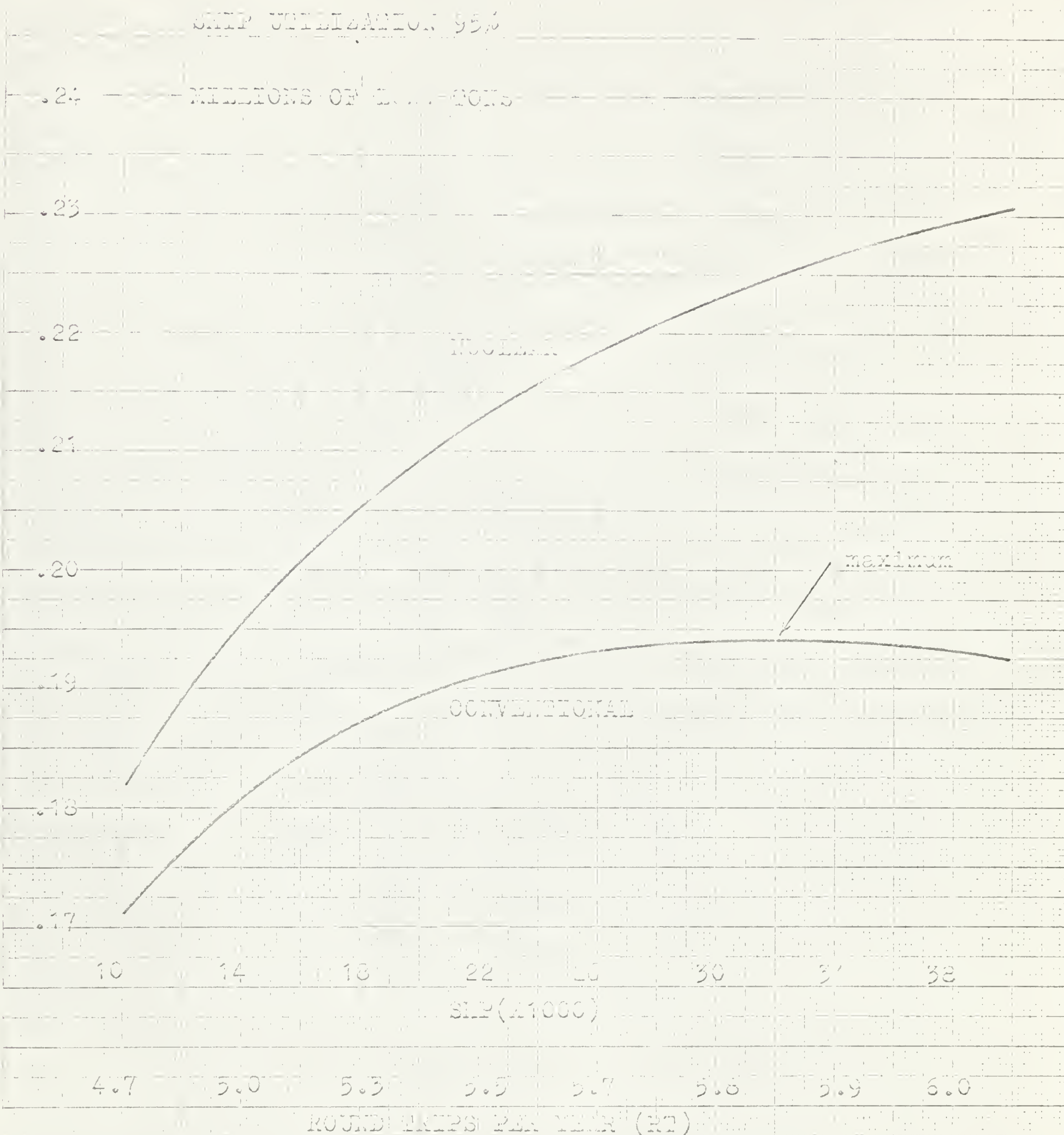


FIGURE 6: COMPARATIVE ANNUAL TRANSPORT CAPACITY

Table XI is a summary of the annual transport capacity characteristics of the two ships.

TABLE XI

ANNUAL TRANSPORT CAPACITY CHARACTERISTICS

	Conventional	Nuclear
WEIGHT SUMMARY		
Displacement	53,500	53,500
Structure	11,576	11,676
Outfit & Hull Engineering	1,881	1,881
Machinery	800	840
Light Ship	14,257	14,397
Deadweight	39,243	39,103
Fuel Weight	2,992	0
Miscellaneous Weight	250	250
Cargo Deadweight	36,001	38,853
RELEVANT FACTORS		
Speed	15.3	15.3
Round Trips per Year	5.04	5.04
Annual Transport Capacity	181,460	195,835
Seadays per Year	328	328
Portdays per Year	18	18
Repair/Non-charter Days per year	19	19

E. Annual Capital Recovery Factor

Comparative annual capital recovery factors are shown in Figure 7. Since the CRF is a fixed percentage of the total construction cost, the nuclear capital recovery is significantly higher than the conventional.

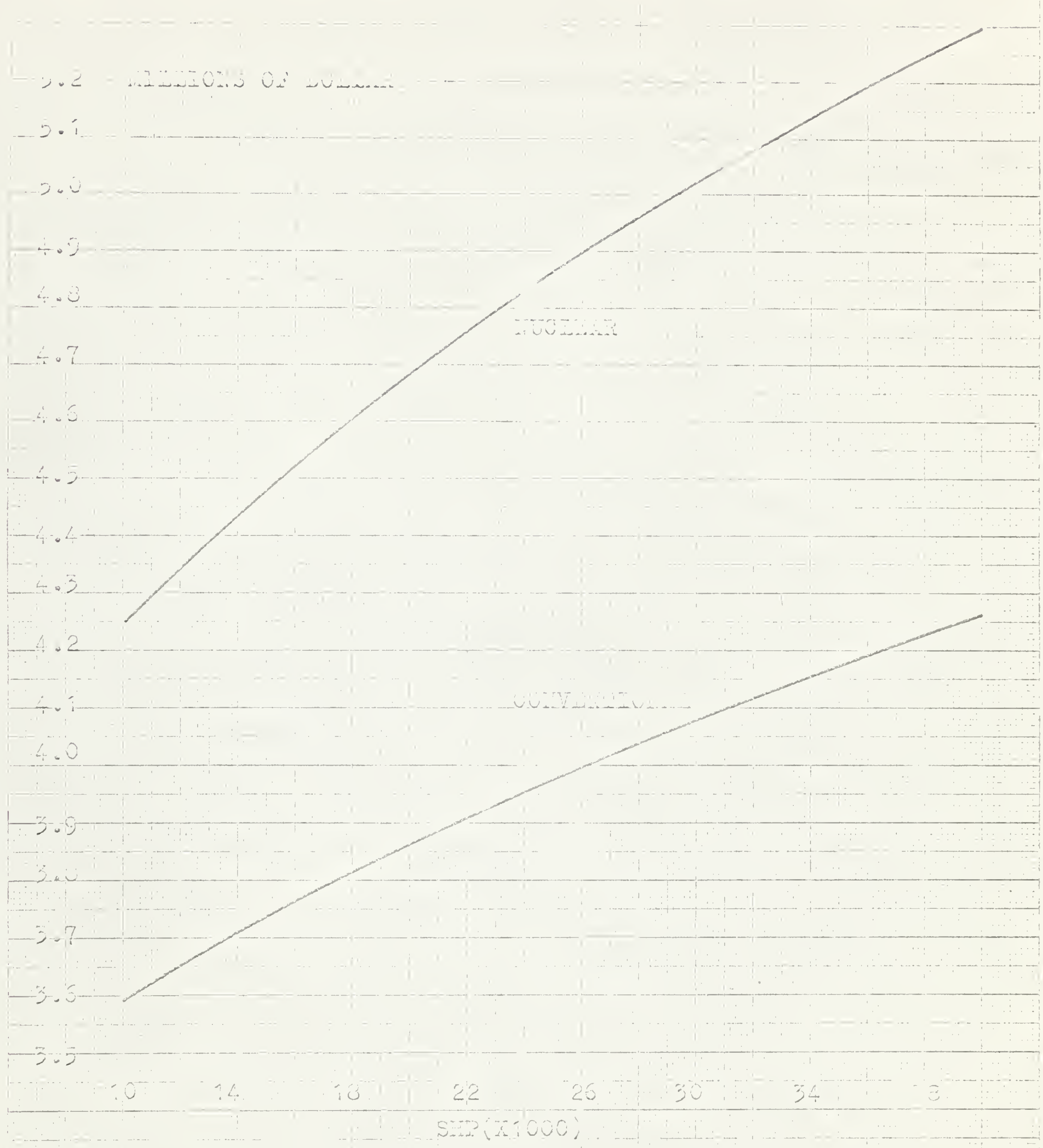


FIGURE 7. COMPARATIVE ANNUAL CAPITAL RECOVERY FACTORS

D. Measure of Merit

Before presentation of the measure of merit analysis, a statement of clarification and purpose is needed lest the knowledgeable community misinterpret the results. The author is painfully aware that the required freight rates set forth in this section of the analysis are not typical of commercial rates available on the world market for bulk cargoes. That they are not typical is a reflection on the pathetic competitive state of the United States merchant marine and do not invalidate the findings of this study on that ground. It must be borne in mind that this is a comparison of unsubsidized and unsupported ships and it is the principal purpose of this comparison to investigate the competitive posture of a nuclear powered bulkcargo vis-a-vis a conventional one.

Figures 8 and 9 present the comparative measures of merit for ship utilizations of 70, 80, 90 and 95%. Required freight rate (RFR) is the ordinate in dollars per long ton and is obtained by dividing the sum of annual operating cost and capital recovery cost by the annual transport capacity.

As stated in the concepts of this study, to be competitive, the minimum RFR of the nuclear ship must be equal to or less than the minimum RFR of the conventional ship. It is seen that at no point over this range of utilization does the nuclear minimum RFR become equal to or less than the minimum conventional RFR for the same utilization. The nuclear alternative is not competitive with the oil fired ship. It can be said that as power is increased, the competitive gap is closed and that if the need existed for sufficiently high power, the nuclear ship would be the better alternative. It can also be observed that as ship utilization increases, the locus of economic cross over moves to the advantage of the nuclear ship.

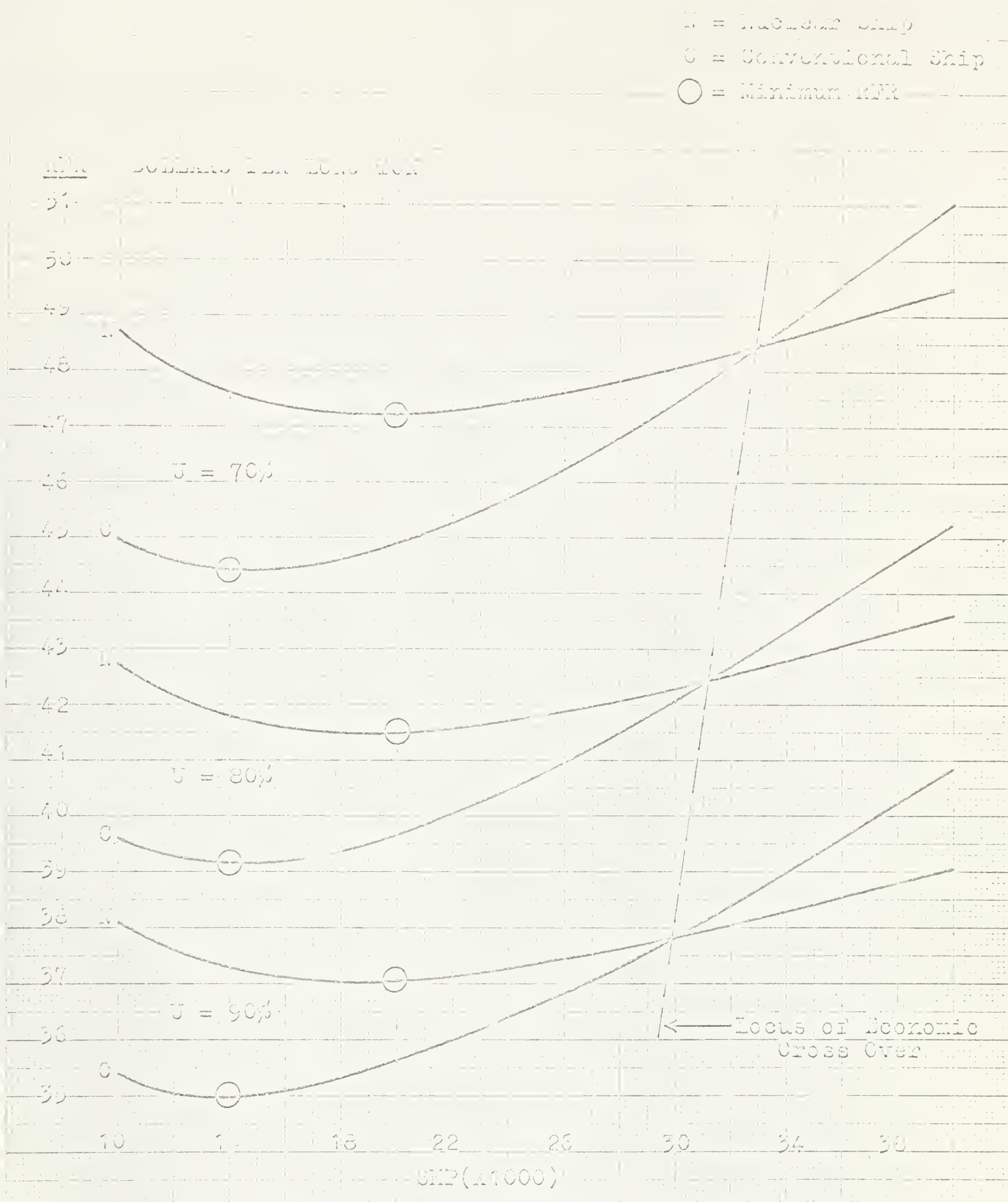


FIG 8: COMPARATIVE MEASURE OF MERIT

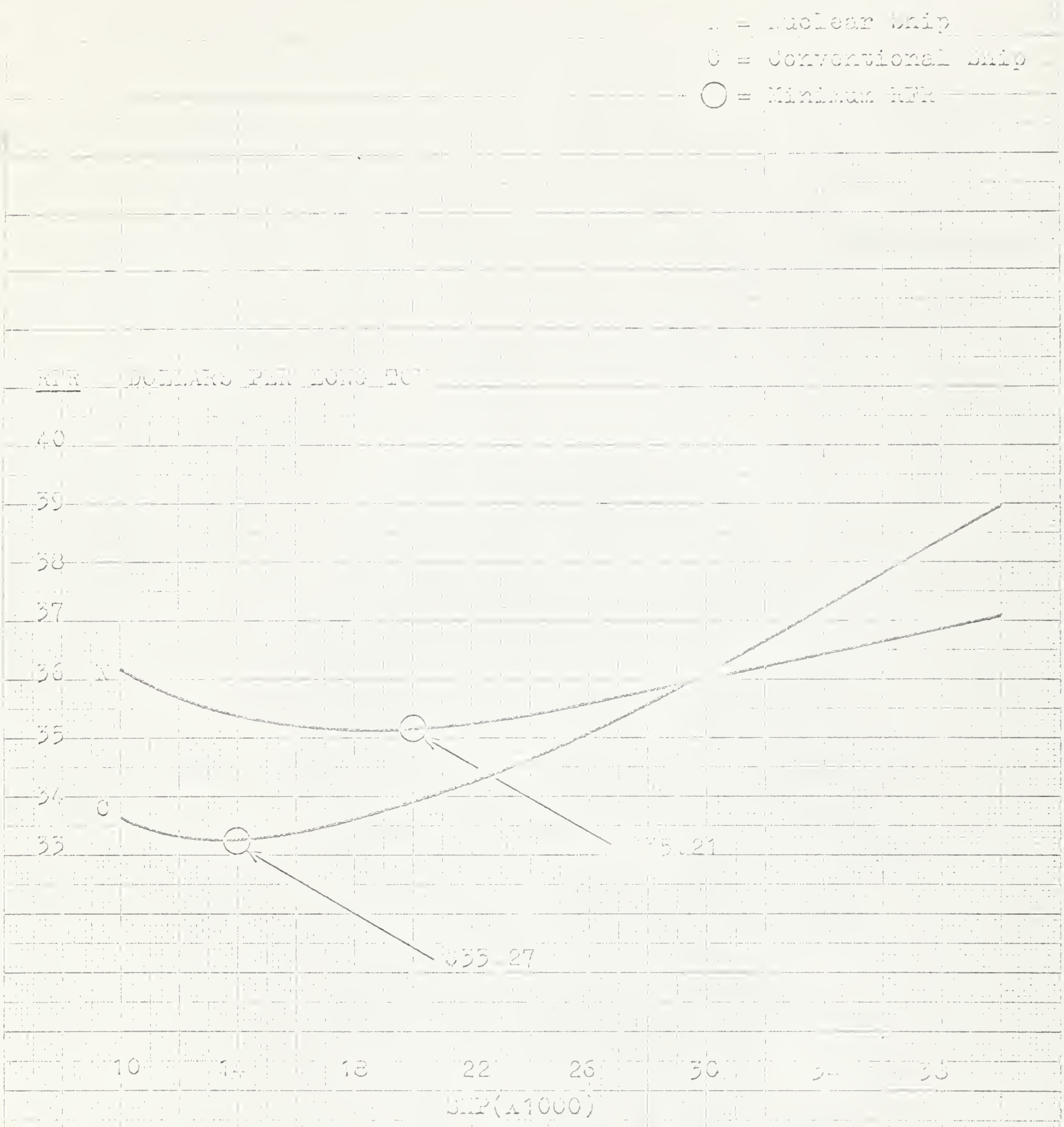


FIGURE 9: COMPARATIVE MEASURE OF MERIT AT 95% SHIP UTILIZATION

Table XII is a consolidated economic analysis of the defender and challenger.

TABLE XII

CONSOLIDATED ECONOMIC ANALYSIS

	Conventional	Nuclear
Construction Cost	$21,205,840	$25,383,232
Annual Operating Costs:		
Wages	$585,000	$643,500
Subsistence	30,030	30,030
Maintenance & Repair	177,068	177,068
Stores & Supplies	18,507	18,507
Total Insurance	217,280	269,517
Overhead & Miscellaneous	50,642	50,642
Port Expenses	26,613	26,613
Fuel	373,596	246,658
Depreciation	848,233	1,015,329
Total: Annual Operating Cost	$2,326,969	$2,477,864
CRF	0.1750	0.1750
Capital Recovery Cost	$3,711,022	$4,442,065
Total Annual Cost	$6,037,991	$6,919,929
Annual Transport Capacity (LT)	181,460	195,835
RFR ($/LT)	$33.27	$35.34
Ratio: Nuclear RFR / Conventional RFR	1.06	

C. Summary

An inspection of the economic analysis presented in Table XII discloses an important fact. With the single exception of wages, all costs that are higher for the nuclear ship are directly related to construction cost, and within construction costs, the predominant factor is the difference between the cost of the nuclear machinery plant and the conventional machinery plant.

The advantages of fuel cost and transport capacity make it unnecessary that the nuclear machinery plant cost be equal to the conventional machinery plant cost before economic parity is reached. A reduction of 25-30% would be enough. The point is however, that the cost of the secondary system of the nuclear machinery plant is relatively fixed; therefore, the reduction would have to come almost entirely from a decrease in the cost of the nuclear steam supply system. It is not realistic to think that a reduction of this magnitude will happen.

Although the cost of the nuclear steam supply system would decrease through the economies of volume production and the learning functions associated with any new technology, they will be offset by rising labor and material costs. Discussions with vendors indicate that nuclear costs are rising faster than conventional costs because of the special skills and exotic materials associated with nuclear technology.

In the opinion of the author, merchant ship nuclear power must look to factors other than reduction in nuclear machinery plant cost for its future. Specifically, it must find that environment where high power and utilization are required because these factors are the sine qua non for competitive marine nuclear propulsion.

PART 7.
SENSITIVITY ANALYSIS

A. Purpose

The summary of the preceding part of this study concluded that construction cost was the cardinal cause for the non-competitive position of the nuclear alternative. The purpose of this part is to first, determine the magnitude of the reduction of nuclear construction cost necessary to achieve a competitive status and second, to examine the economic environment of the competition in order to identify those factors which influence the potential attainment of this status.

This purpose is achieved by a sensitivity analysis of those model inputs which are realistically changeable. Many analyses were conducted; the majority were discarded because they were not clearly realistic expectations or the variation of inputs could not be accepted in isolation from other factors. All analyses described in this part were conducted at a ship utilization of 95% for reasons previously explained.

B. Construction Cost Reduction Analysis

In this analysis, the construction cost of the nuclear ship was reduced from 0-25% in 5% increments with all other factors held constant. The purpose of the analysis was to determine the percentage reduction necessary to place the nuclear ship on a competitive par with the conventional. The results are presented in Figure 10. As indicated in the results of operation, the minimum RFR for the nuclear ship occurs at about 20000 SHP; this minimum RFR power is shown as a vertical line in Figure 10 for reference. As the figure indicates, a reduction of about 7% in the construction cost of the nuclear ship would cause the nuclear RFR to equal the minimum RFR of the conventional ship ($33.27) thus setting the condition for economic parity. A reduction of 7% equates to about $1.9 million dollars but represents only 40% of the difference in construction costs of the two ships. The con-

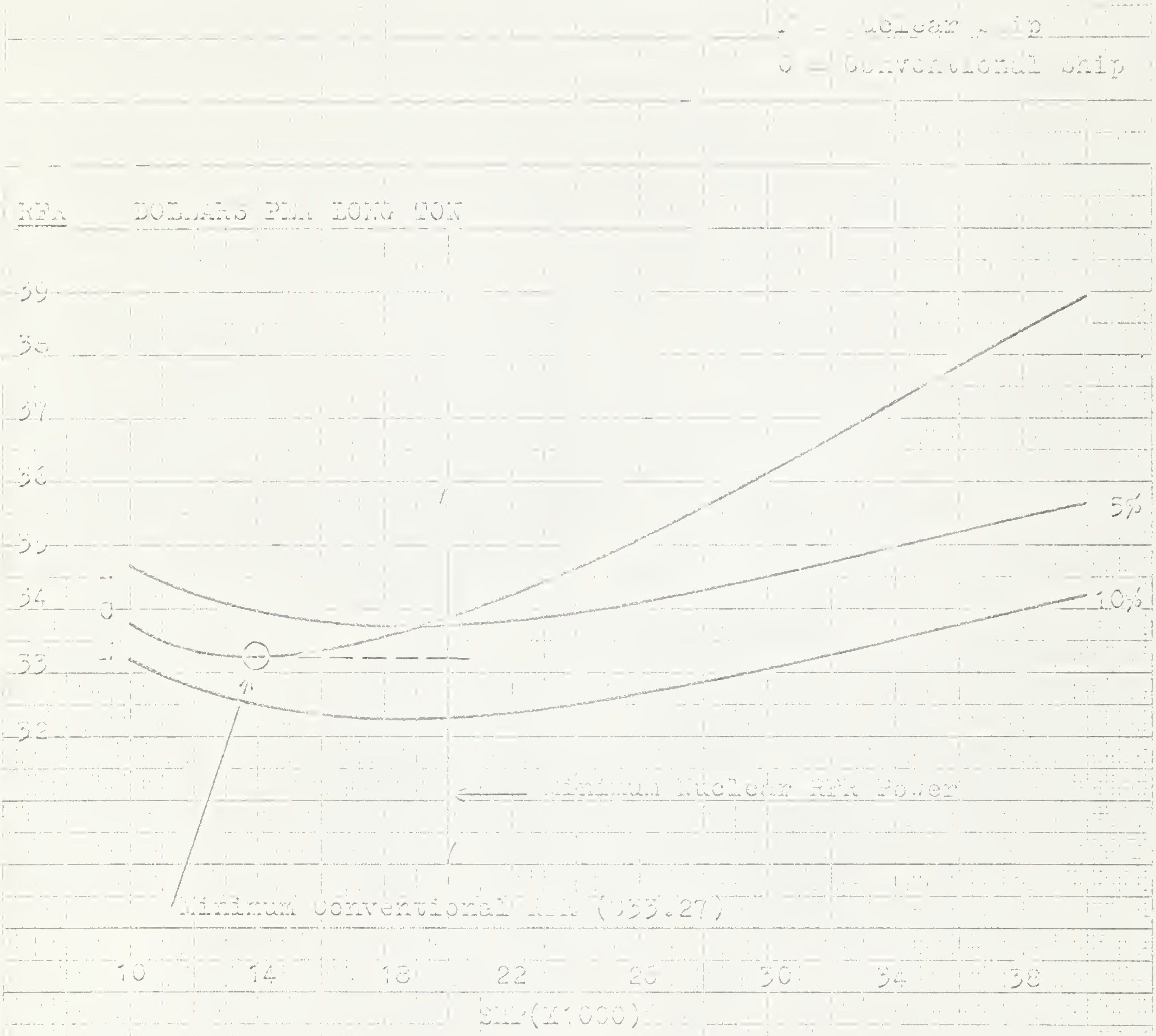


FIGURE 10: CONSTRUCTION COST [illegible] ANALYSIS

clusion is, of course, that it is not necessary for the construction cost of the nuclear ship to be equal to the construction cost of the conventional before economic par is reached. The causes for this are the decrease in costs directly dependent on construction cost such as insurance, depreciation and capital recovery plus the inherent advantages of nuclear fuel cost and annual transport capacity.

C. Title X (H.R. 782) Analysis

This analysis is an examination of Secion 1005 of H.R. 782 (Appendix A) which authorizes the Secretary of Commerce to:

"...become a party to...contracts between the applicant and others for the construction of the proposed nuclear-powered merchant ship, and may agree in such contracts to pay the contractor (not the applicant) all of, or part of, the excess of the cost of constructing the proposed ship in the United States over the estimated fair and reasonable cost of constructing a comparable conventional ship in the United States..."

The analysis assumes that the Secretary of Commerce pays all of the excess described above, but does not include the provision of the bill for the waiver or reduction of AEC charges for the use of source and special nuclear materials (i.e. "use charges" described in Part III) in the operation of the completed ship for the first five years of operation.

The results of this analysis are presented in Figure 11. It can be seen that if the construction cost offset provisions of the bill were utilized to the fullest extent authorized, the nuclear ship is economically superior to the convention, even without reduction in first fuel costs. The conclusions of this analysis are, that for the type ship under study and the assumptions set forth, the proposed legislation contains "overkill". As a matter of interest, the support provided by this bill at the minimun RFR point (20000 SHP) is about $4.7 million dollars exclusive of fuel offset.

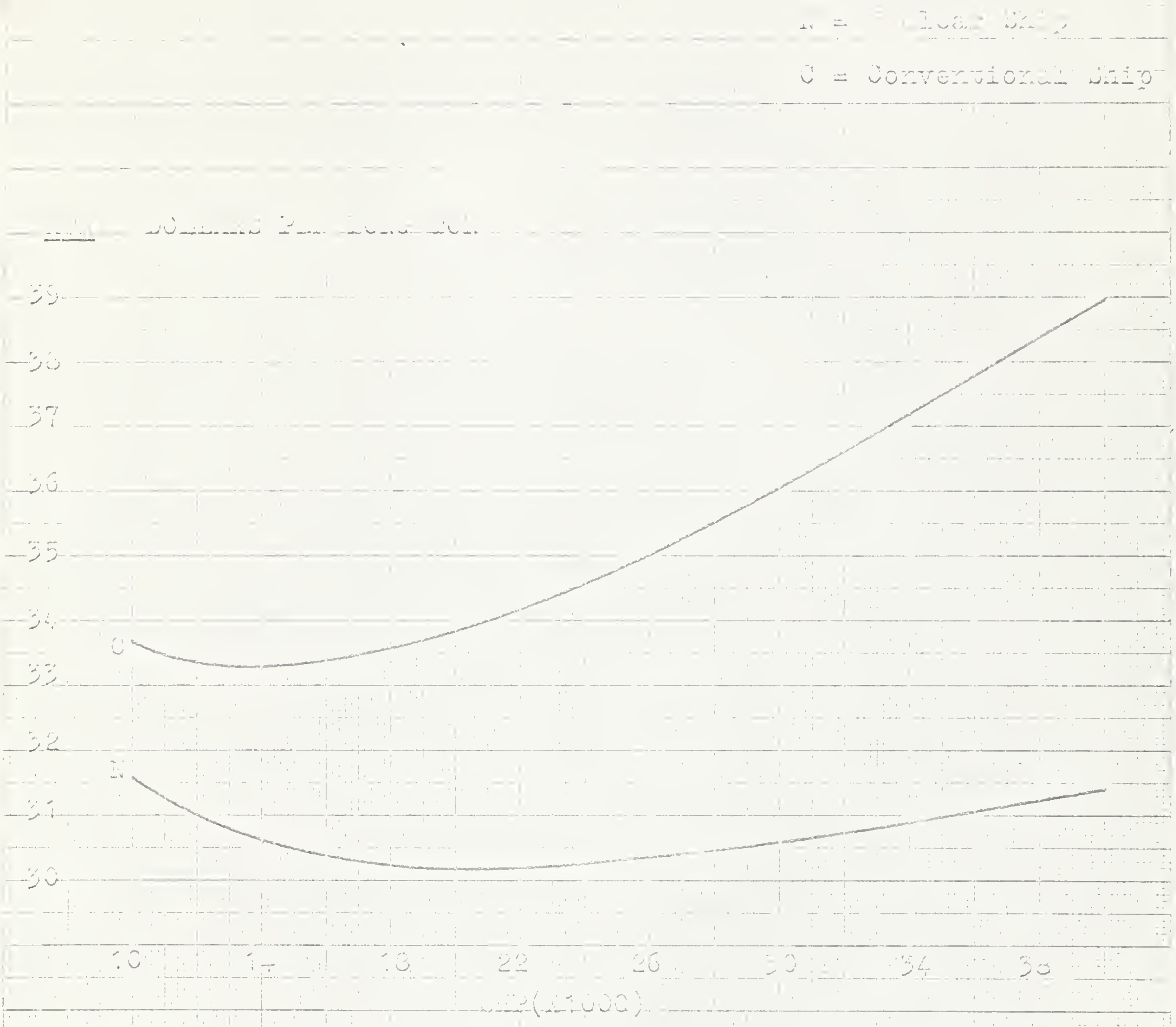


FIGURE 11: TITLE X ([illegible] 782) ANALYSIS

D. [illegible]

The cumulative average cost of identical ships constructed in serial production at a shipyard is indicated by the following expression:

$$C_n = C_1 * N^{-b}$$

Where: C_n = the cumulative average cost per ship for N ships

C_1 = the construction cost of the first ship

N = the number of ships to be constructed

b = the learning coefficient which varies with the complexity of the ship type and prior experience of the shipyard

Couch[35] suggests a value of of 0.97 for b for general cargo ships built in United States shipyards. This equates to a learning function of 93.5%; in other words, each time the number of ships constructed doubles, the cost of each ship is reduced by 93.5%.

Using these relationships, the construction cost of the nuclear ship was reduced according to the learning function associated with multiple ship acquisition and the results presented in Figure 12. It can be seen that the RFR is significantly reduced for multiple buys. The quantitative effect of multiple buy is presented in Table XIII below.

TABLE XIII

MULTIPLE SHIP CONSTRUCTION COSTS

Number of Ships in Contract	Construction Cost	Ratio of Average Cost per Ship to Cost of Single Ship
1	$26,765,584	1.000
2	$25,025,152	0.935
3	$24,060,016	0.897
4	$23,397,904	0.874
5	$22,896,896	0.856

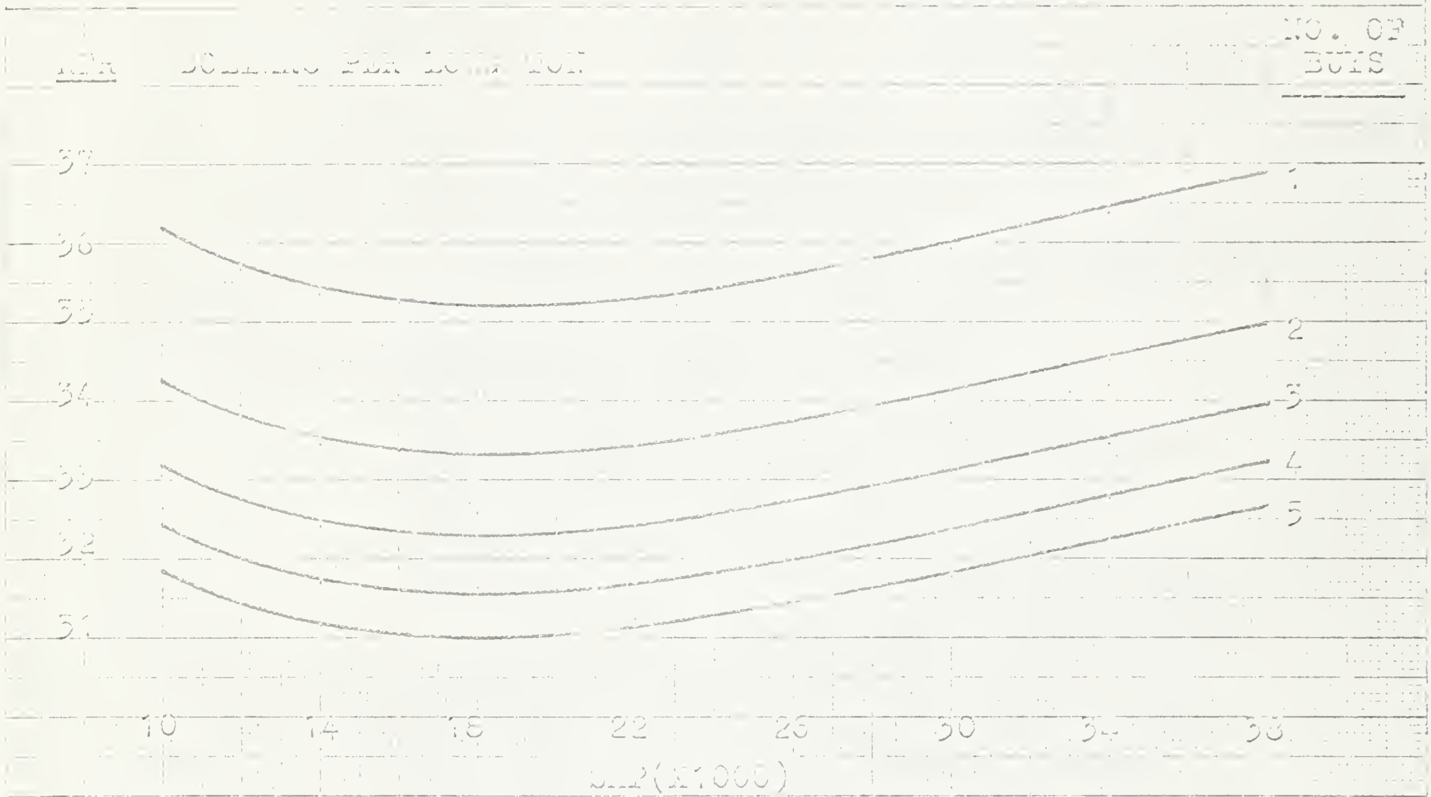


FIGURE 12F MULTIPLE SHIP ACQUISITION

Obviously, the economies of multiple ship acquisition are as available to the conventional ship as they are to the nuclear. The point of this analysis is to indicate that multiple buy is one of the ways by which the construction cost of the nuclear ship can be reduced.

E. Round Trip Distance Analysis

Round trip distance analysis is a powerful demonstration of the effect of one of the economic environment factors on the competitive position of the nuclear ship vis-a-vis the conventional. In this iteration, the round trip distance is varied over a range of 6,000 - 24,000 nautical miles in increments of 6,000 miles. The results are indicated in Figure 13. The ordinate of this figure is the RFR of the nuclear ship divided by the RFR of the conventional; thus a ratio of 1.04 means that the freight rate of the nuclear is 4% higher than the conventional, a ratio of 0.97 means that is is 3% lower and 1.00 is parity.

It can be seen that as voyage distance is decreased, the advantage moves decidedly in favor of the conventional ship. Secondly, at any given voyage distance, as power is increased the ratio decreases moving the advantage towards the nuclear ship. A ratio of 1.00 is reached only at high power levels and for distances of 6,000 and 12,000 miles is never reached at all.

A review of those cost factors either directly or indirectly dependent on voyage distance is helpful in understanding the power of this variable:

Port Expenses
Fuel Cost
Annual Operating Cost
Total Annual Cost
Required Freight Rate
Fuel Deadweight
Cargo Capacity
Annual Transport Capacity
Round Trips per Year
Seadays per Year
Portdays per Year

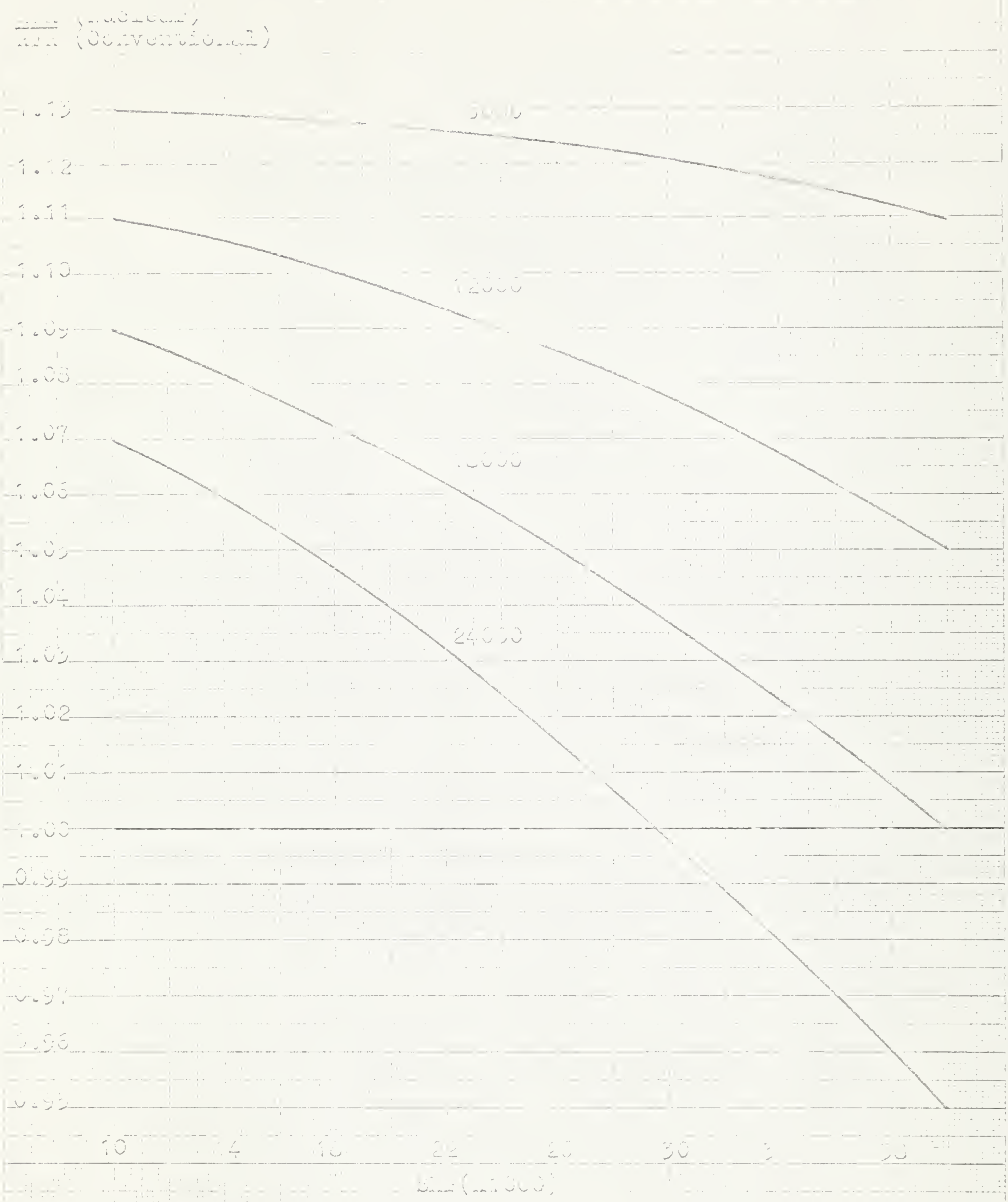


FIGURE 13: ROUND TRIP DISTANCE ANALYSIS

Table XIV below presents a revealing indication of the magnitude of change in some of these factors as the result of change in voyage distance.

TABLE XIV

EFFECT OF CHANGE IN VOYAGE DISTANCE

(at 14000 SHP)

COST FACTOR	24000 MI	6000 MI	CHANGE
Port Expenses*	$ 26,613	$ 92,009	+$65,396
Oil Fuel Cost	$373,596	$322,903	-$50,693
Nuclear Fuel Cost	$246,658	$213,189	-$33,469
Oil Fuel Weight	2,992	748	- 2,244
Nuclear Fuel weight	0	0	0
Conventional Cargo Capacity	36,001	38,245	+ 2,244
Nuclear Cargo Capacity	38,853	38,853	0
Round Trips per Year*	5.04	17.43	+ 12.39
Sea Days per Year*	328	284	- 44
Port Days per Year*	18	62	+ 44

*Same for both alternatives

The decrease in voyage distance is traumatic to the nuclear ship. The shorter the distance, the less fuel the conventional must carry; the less fuel she must carry, the more space is available for cargo. The other somewhat "hidden" effect is equally important: although the nuclear ship still holds a fuel cost and cargo capacity advantage at 6000 miles, the number of days at sea has been reduced significantly and each day the ship is not at sea cuts into this advantage.

This analysis adds another dimension to the criteria for nuclear ship competition — the nuclear ship must be at sea to exploit her advantages of fuel cost and transport capacity. Over short routes, high power and high ship utilization are not enough. The reactor must be utilized.

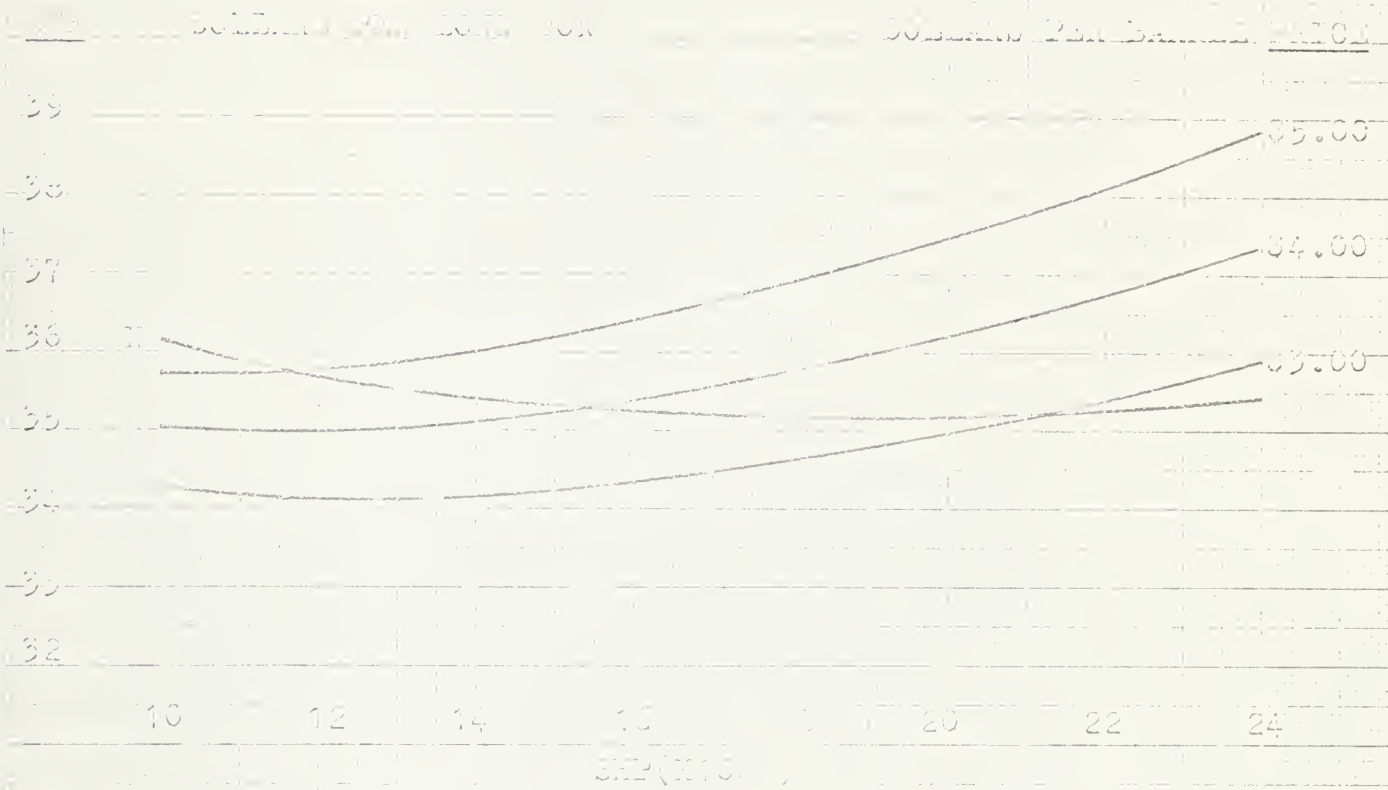
F. Bunker "c" Price Analysis

Residual fuel oil is a by-product of the crude oil refining process and the use of bunker "c" on conventional ships is one of the principal uses of residual fuel. The basic determinants of the price of residual oil are the cost of transportation, the demand for refined oil products in relation to the cost of reducing the yield of residual in the crude oil cracking process, the supply and demand within a given geographic area and most important, the price of competing fuels such as natural gas and coal.[29]

For the purposes of this study, it has been assumed that the price of bunker "c" on the east coast of the United States is $2.15 per barrel based on information from the U.S. Coast Guard. For reasons that will be best explained in the following Part, this price will certainly increase with time.

The purpose of this analysis is to find that price of bunker "c" that would of itself, cause the nuclear ship to be competitive with the conventional alternative. The price of bunker "c" was varied in the model from the assumed value to $5.00 per barrel in increments of $0.50 while holding all other factors constant.

The results of this analysis are plotted in Figure 14. The curve labeled "N" is the graph of the nuclear ship RFR over the power range investigated. The other curves are conventional RFR graphs for the bunker "c" price indicated. With the minimum nuclear RFR occurring at 20000 SHP, it can be observed that if the price of bunker "c" were to increase slightly above $4.00 per barrel, the ships would be on a competitive par. It is of course, a static analysis as far as the nuclear ship is concerned. As indicated previously, costs for nuclear technology are rising faster than for conventional technology and to the extent that this trend continues, the analysis has value only in a static sense. Nevertheless, this factor is changeable, will change and is one of increasing importance as fossil fuel reserves decrease.


37
36
34
32
10
12
14
20
22
24
$4.00

PART VII.

FORECAST FOR FOSSIL FUELS

A. [illegible]

A feasibility study which compares two existing technologies would be incomplete without some examination of the future, particularly when one of the two technologies is relatively impermanent. The purpose of this part of the study is to assess the longevity of fossil fuels by reviewing some of the estimates and forecasts of fossil energy supply and demand. The knowledge that fossil fuel reserves are finite is intuitive; the quantitative value of remaining reserves is something of a shock.

B. United States Reserves

In a letter to the Chairman of the Atomic Energy Commission in March of 1962, the President of the United States said:

"...we must extend our national energy resources base in order to promote our Nation's economic growth. Accordingly, the Atomic Energy Commission should take a new and hard look at the role of nuclear power in our economy..."[36]

The Commission responded in November of the same year with a report entitled, "Civilian Nuclear Power - A Report to the President". The data that follows with respect to U.S. fossil energy reserves is taken from that report.

The Commissions assessment of the cumulative consumption and resources of fossil fuels in the United States is presented in Figure 19. The ordinate of the figure is in "Q's" (for quintillion). The value of one Q is the equivalent of one billion-billion British Thermal Units (BTU) or the energy available in 40 billion tons of average high-grade coal. The fossil energy resources of the U.S. are indicated by the blocks on the far right of the figure. The estimate of 191 Q is that of the Department of the Interior, while that of 20-30 Q is derived or implied from reports by the Committee on Natural Resources of the National Academy of Sciences, the Committee on Interior and

Insular Affairs of the United States Senate and Geological Survey Bulletin 1136.

The difference between the two estimates is very large and is apparently due to variation in the estimates of "marginal resources" such as coal in thin veins or at great depths, differences in the feasibility and costs associated with recovery of marginal resources and differences in assumptions about recovery efficiency. The Department of the Interior believes that the 6Q of known reserves shown in their estimate is recoverable at present costs with known technology and perhaps an additional 25 Q of the 124 Q of marginal and undiscovered resources can be recovered at 10-15% higher costs provided that the technologies associated with exploration and extraction are improved through research.

Curve A is an extrapolation of the experience of the past 60 years during which the average increase in annual fuel consumption was 2.04%. Curve B is an extrapolation of an estimate for the year 1980 made by the National Fuels and Energy Study of the Committee on Interior and Insular Affairs, U.S. Senate. The extrapolation is based on an annual rate of population growth of 1.75% and a 1.5% annual rate of increase in per capita use. Curve C assumes a decrease in population growth rate and a decrease in the rate of per capita consumption

The Commission's report assesses these data as follows:

"As can be seen, different combinations of the estimates of fuel reserves and of cumulative uses would predict that, if no supplementary forms of energy were utilized, we would exhaust our readily available, low-cost supplies of fossil fuels in from 75 to 100 years and our presently visualized total supplies in from 150 to 200 years." 36

This assessment seems to be based more on Curve C than on a mean of the three. In the opinion of the author, it is a conservative forecast for the remaining life span of fossil energy reserves in the United States.

*1: Marginal and Undiscovered Resources
*2: Known Reserves
*3: Prior Consumption

FIGURE 15: CUMULATIVE ENERGY CONSUMPTION VS FOSSIL FUEL RESOURCES IN THE UNITED STATES[30]

[illegible] there is a further reduction in the confidence for the future of fossil fuels arising from the fact that fossil fuel forecasts are notoriously shifty. In 1947, the U.S. Bureau of Mines and the U.S. Geological Survey jointly submitted a statement to the Senate Public Lands Committee which said:

"Reserves of bituminous coal, sub-bituminous coal, and lignite in place in continental U.S. are estimated at about 3.1 trillion tons as of January 1944, sufficient for nearly 5400 years at a yearly rate of production approximating the maximum rate in the past - 600 million tons - and with current mining losses." [36]

This statement coincided to an extraordinary degree to an estimate published in 1909 by M.R. Campbell, which placed the amount of coal of all kinds in the United States within 3000 feet of the surface at 3.1 trillion tons. The 1947 report put the heat value of its estimate at 67 Q. Comparing this with the 6 Q of known reserves estimated by the Interior Department shown in Figure 15, the U.S. has revised its estimate of known reserves downward by a factor of more than ten in 15 years.[36]

C. World Reserves

Following the 1947 report, the Atomic Energy Commission requested Mr. Palmer Putnam, noted authority on energy sources and reserves, to conduct a study of the maximum plausible world demands for energy over the next one hundred years. Putnam's analysis concentrated on the two factors that are the basic determinants of global energy demand - population increase and average per capita consumption of energy. Putnam took the viewpoint of a hypothetical trustee of the world's energy bank; consequently, his analysis would represent the cautious approach to such a charter.

Putnam's maximum plausible curves of cumulative fuel consumption are presented in Figure 16. They are based on the expectations that (1) world population will rise

to be between 5000 and 8000 million by 2050 and (2) that the annual rate of growth of the demand for usable energy output will be between 3 and 5%. As in Figure 15, the ordinate in Figure 16 represents cumulative consumption. The curved areas of the figure represent the rise in cumulative consumption of energy corresponding to the assumed annual growth rates of 3, 4 and 5%. The upper limit of each area corresponds to a population growth culminating in a world population of 8000 million by 2050 and the lower limit is the assumption for 5000 million by that date.

In addition to forecasting the world demand for energy Putnam estimated the heat content of the total world reserves of economically recoverable* fossil fuels to be as set forth in Table XV below.

TABLE XV

TOTAL WORLD RESERVES OF FOSSIL FUELS[36]

Coal	32.0 Q
Oil & Gas	5.0 Q
Oil-Shale	1.0 Q
Tar-Sand	0.02 Q
Total	38.02 Q

Comparing Putnam's estimates of energy supply and demand indicates an outage of economically recoverable fossil fuel reserves at some time in the first quarter of the next century unless there is a significant discovery of conventional sources or a significant shift to nuclear energy.

As a matter of interest, Putnam estimated that of the 32 Q of total world reserves of coal, the United States held 6, which is the same figure reported by the Interior Department as "known resources" in Figure 15.

*Recoverable at costs no higher than 1.3 times 1950 costs for oil and gas and no higher than twice 1950 costs for all other fuels.

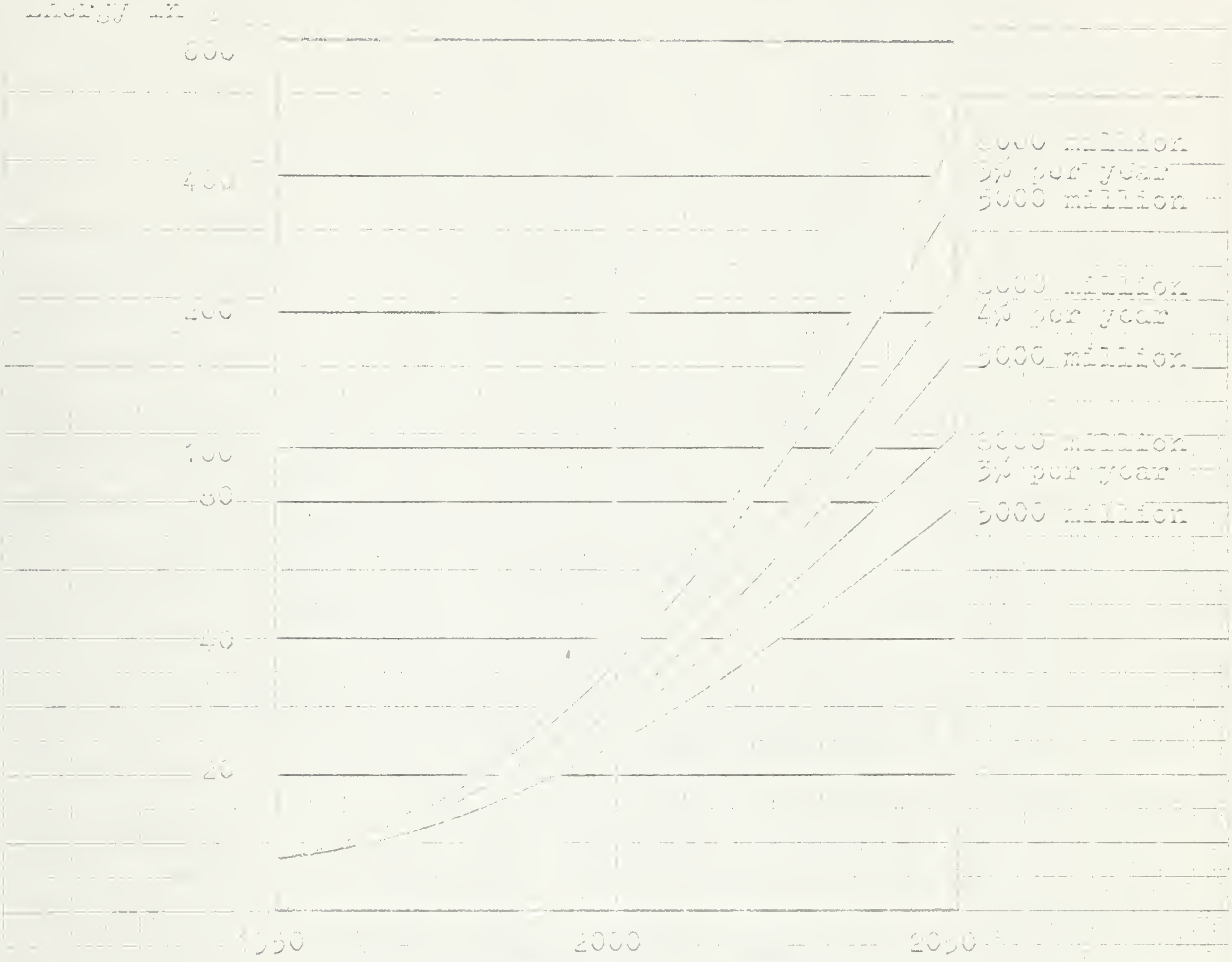


FIGURE 16: [illegible] CONSUMPTION

Having reviewed what might be considered about the worst case for total fossil fuel supply and demand, an examination of the oil sector is in order since the thrust of this study is the economic comparison of a merchant ship powered by nuclear energy and one propelled by residual oil.

D. United States Oil Reserves

The proven petroleum reserves in the continental U.S. were estimated to be 26 billion barrels in 1950 while undiscovered oil was estimated to be between 46 and 60 billion barrels. Annual U.S. consumption during this same time period was about 2.5 billion barrels.[35] Were it not for the hugh imports of crude oil from other countries, the United States would be in difficulty. The heat content of both proved and undiscovered oil reserves is about 0.5 Q. A review of Figure 15 indicates that oil reserves are a minute fraction of our total fossil reserves.

E. World Oil Reserves

Putnam's estimates of the heat content of the world reserves of oil and gas considered to be recoverable at costs no higher than about 1.3 times 1950 costs are summarized in Table XVI below.

TABLE XVI

WORLD OIL-GAS RESERVES[36]

	Proved	Undiscovered	Total
United States	0.25	0.25	0.5
Remainder Western Hemisphere	0.11	0.9	1.0
Soviet Union	0.04	1.3	1.3
Middle East	0.57	1.1	1.7
All Other Regions	0.02	0.5	0.5
Total	0.99 Q	4.05 Q	5.0 Q

To make matters even more critical for oil, the consumers of world energy are demonstrating an ever-increasing preference for liquid and gaseous fuels. This trend is indicated by Figure 17 in which the percentage of world consumption of energy supplied by the four major sources is shown for three time periods. The increasing use of oil derivatives is undoubtedly related to the staggering increase in the amount of transportation that has occurred during the past fifty years.

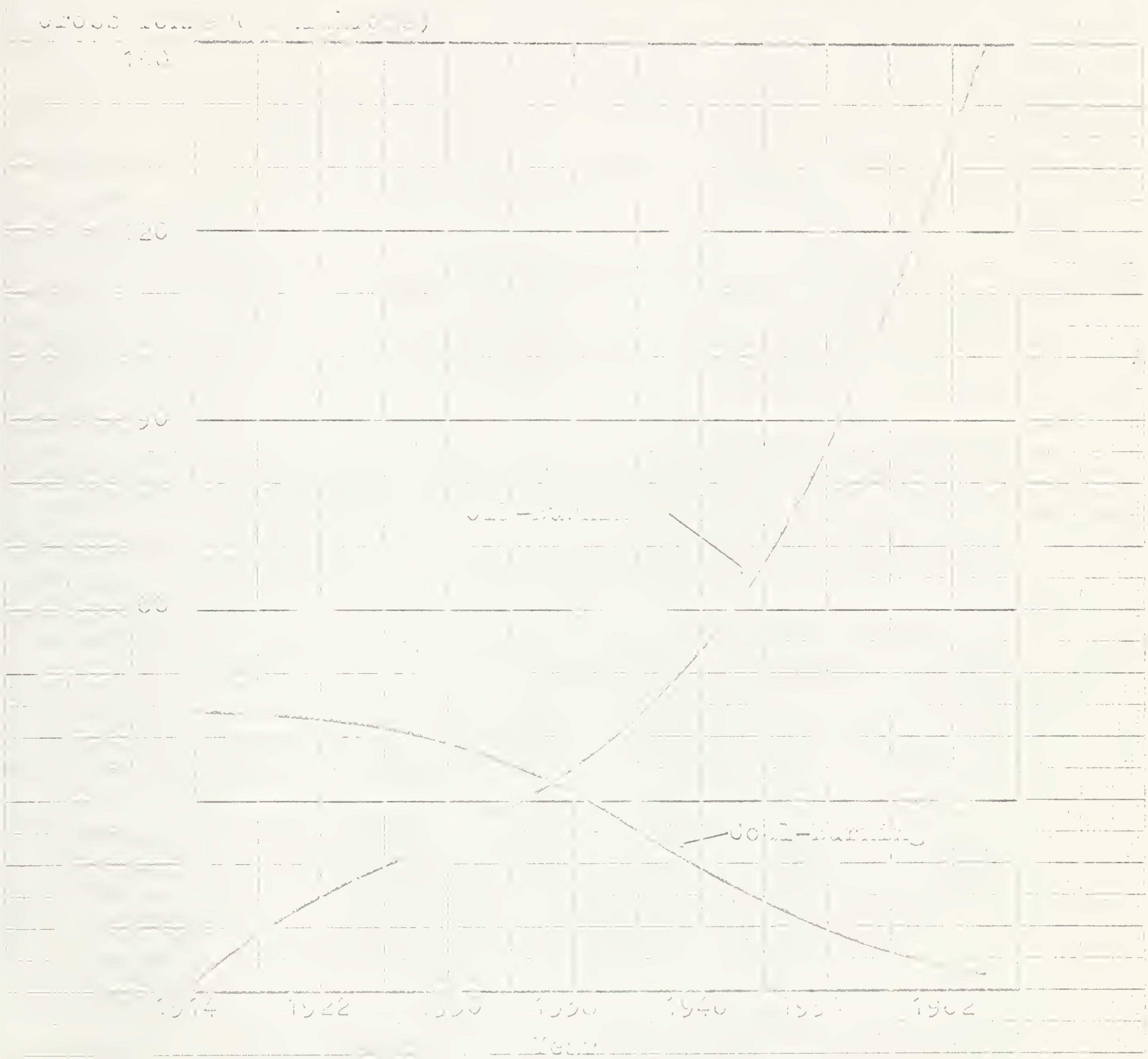
The reasons for the shifting preference to oil and gas fuels are to be found in hard-headed economics. Liquid and gaseous fuels are easier and therefore cheaper to extract, handle and transport than their solid counterparts. In addition, there is greater economy in conversion to mechanical work. In the case of coal versus bunker "c" oil for example, the average heat value of high-grade coal is about 12,000 BTU/pound while that of bunker "c" is 18,500 BTU/pound.[39]

With specific respect to the fuel preference of conventional ships, it is not an overstatement to say that it is a rare occurrence to pass a ship on the seas today that is not burning oil. Figure 18 shows the metamorphosis of merchant shipping from coal to oil from 1914 to 1964. The ordinate is the gross tonnage of the world's ships. It can be seen that as the tonnage of world ships increased from 45 million tons in 1914 to 153 million tons in 1964, oil has become the principal fuel to the almost total exclusion of coal.

Paradoxically, on 11 August 1968, the Department of Transportation released a forecast of commercial shipping technology which stated that by the year 2043, ocean borne trade will total 55 billion tons - about 17 times what it is now.[16] It also stated that through 2043, the major portion of ocean-going trade will continue to be carried by conventional ships.[45] Barring the improbable discovery of a monumental supply of oil or a major shift by other users of oil to some other form of energy, one has to wonder where these ships will find the means of conventional propulsion.

C = Coal
O = Crude Oil
G = Natural Gas
H = Hydro-electricity

FIGURE 17. [illegible] [56]


Coal-burning
1922
Year

[illegible]

A reasonable set of conclusions from the data presented in this part of the study would seem to be as follows:

1. The world is running out of fossil fuel energy. It is not important that we be able to pinpoint the exact year when this will happen even if we could; it is enough to know that it will happen and not too distantly.

2. The world is running out of oil faster than other energy forms because consumers are showing an increasing preference for oil and because there is less of it. If the present trend continues, oil production will have to double every twelve years and reserves will be exhausted in less than a century.

3. The impact of oil depletion falls most heavily on transportation which relies to a majority extent on oil derivatives as its source of motive energy. The effect of oil depletion on automobiles and aircraft boggles the imagination.

4. Within transportation, oil depletion will have a staggering effect on ships which rely almost exclusively on residual oil for propulsion.

5. As oil reserves decline, the price of oil products will increase as exploration and extraction costs rise in the search for residuals and the laws of supply and demand take effect.

6. As the price of oil increases, society will have to make a choice between replacing oil by conversion of other fossil fuels such as the hydrogenization of coal, or the conservation of the remaining reserves through the exploitation of nuclear energy.

CHAPTER [illegible]

SUMMARY AND RECOMMENDATIONS

Nuclear propulsion has three basic economic advantages to offer commercial marine application: greater cargo capacity, lower fuel cost and relative refueling freedom.

This study finds that there is no present promise in these advantages for the contemporary merchant ship. At the same time, the study indicates that if there is a competitive environment for merchant ship nuclear power, it will take the form of a high power, long trade route ship designed and constructed to minimize in port turnaround time.

It is equally important and an essential part of this environment that there be a demand for such a ship in order to attain the high utilization required to put the nuclear ship on a competitive par with the conventional alternative.

Finally, the ship must possess an inherent reliability of men, material and machinery so that high utilization can be delivered. If these conditions are not met, there will be no place for nuclear power in the merchant marine of the United States until the rising cost of residual oil leaves no alternative.

The decision to make a more ambitious entry into the field of merchant ship nuclear power rests then, on the extent to which these conditions exist or can be perceived. There are indications that they are emerging.

The speed of ships engaged in ocean commerce is constantly increasing. The average speed of U.S. cargo ships was 8-10 knots in 1920, 14-16 knots in 1940 and 18-20 knots in 1960. Present planning for some ship construction calls for ships capable of 25 knots.[31] Whether or not the projections for 30 knot ships in the early 1970's are valid or not is a matter for speculation, but the trend towards speed over the past fifty years is a matter of fact and where there is a requirement for high speed, there is a requirement for high power.

[illegible] high [illegible] of any size merchant ships requires high power, speed is not the only source of requirement for power. Large ships require large power and ship size is increasing. On 1 November, 1968, contracts were signed in the [illegible] of the Maritime Administration between the General Dynamics Corporation and the Lykes Brothers Steamship Company for construction of three ships representing the [illegible] cargo carrier freight ships ever built. Each ship will be 875 feet in length and each will have a deck cargo space equivalent to two football fields in length and 75 feet wide. The ships can carry up to 2.75 million cubic feet of cargo, reportedly the equivalent of 17 modern conventional carriers of the C4 design. They are capable of lift-on, lift-off barge or containerized, palletized or liquid cargoes. Scheduled to complete in 1971, these versatile ships are designed to cruise at 20 knots and above.[13]

Seatrain Line, one of the more progressive and profitable shipping corporations, is investing 36 million dollars in the lease of part of the former Brooklyn Navy Yard to build commercial ships. Two large container ships for Seatrain's own operations are scheduled to be built during the first year of operation. The facilities are large enough to construct ships as large as 200,000 ton tankers. Howard M. Pack, President of Seatrains, has declared that Seatrains is in the large ship business.[45]

The Advanced Marine Technology Division of the Litton Systems Corporation has stated that present technology is sufficient to build tankers up to 1,000,000 tons and forecasts that within the next fifteen years, tankers in the 400,000-600,000 tons category will comprise 10% of world tonnage.[45]

In addition to increasing size and speed, the minimization of port turnaround time and increase in ship utilization are receiving world-wide attention. Reduction of in port time is being brought about by the updating of port facilities and the modernization of cargo handling methods.

The [illegible] for this expansion is the container-ship. [illegible], chairman of the Foundation for the Promotion of Port Interests, Rotterdam, stated before the National Defense Transportation Association in Washington that a containership revolution is in progress. He reported that in 1967, some 100,000 containers moved through the Port of Rotterdam alone and that the number was increasing rapidly. Rotterdam now has two sections of its port devoted to container traffic and is constructing a third.

In the United States, construction of the Port of New York's biggest private development which includes a 700 acre containership terminal began in 1968. On land acquired by American Export Industries, the terminal will reportedly be the largest shipping complex in the U.S. The first of three construction stages will require an outlay of $40 million dollars for container marshalling yards, buildings and a bulkhead one mile long capable of accommodating three 1,000 foot ships.

On the West Coast, American Export has leased land for a containership terminal in the Port of Long Beach. This is conceived to be the western end of a land bridge for containerized cargo moving between Europe and the Far East. Cargo arriving at either end of the bridge will be transshipped by rail across the United States bypassing the longer and more expensive passage through the Panama Canal. American Export is also building a containership terminal in Leghorn, Italy.[10] Additional container terminals are under construction in Weehawken, New Jersey, Oakland, California and Hawaii.

The construction of containership terminals is being matched by the construction of containerships. In addition to the Seatrain plans mentioned previously, contracts totaling some $150 million dollars were negotiated between Litton Systems and the American President Lines and the Farrel Lines for three and four container and unitized cargo ships respectively, in December of 1968.[44]

In addition to containerization, unitized and palletized cargo, other methods are being used to shorten in port time and increase ship utilization. These include lift-on/off, roll-on/off and float-on/off concepts. The latter has several variations but all involve the principal of unloading cargo from the high-cost big ships into low-cost small ships. The low-cost small ships then deliver the cargo to the port of discharge while the big ships move on their way to the next port, "cleaning up" as necessary in transit.

Every day spent in port loading and unloading cargo or waiting to be loaded or unloaded decreases the primary utility of ship transportation and thus profits. The signs are that world shipping interests are doing something about it. The goals are cargo handling in terms of hours, not days and a significant increase in the number of days the ship is at sea earning revenue dollars.

These data are the emerging signs that the maritime world is beginning to grasp the concept of a transportation system in which the ship is seen in the perspective of a sub-system whose function it is to move cargo by water, rather than an economic entity in itself. If the needs of this total system concept continue to move towards increasing speed, larger cargo capacity, decreasing turnaround time and higher vessel utilization, it may well be that the ship sub-system that best meets the needs and requirements of this concept will also meet the conditions for competitive merchant ship nuclear power.

This study recommends conditional federal support for a three phase merchant ship nuclear power program:

PHASE I.

A responsible and rigorous research and development program under the direction of the Atomic Energy Commission which will result in a maritime nuclear steam supply system capable of supplying energy to a proven secondary system in the 50,000 - 100,000 SHP range and incorporating those design attributes most important to economic deployment on merchant ships, including:

1. Capability of volume manufacture.
2. Similarity of fuel design to central station power reactors.
3. Light weight.
4. Low volume.
5. High reliability.
6. Simplicity of operation and maintenance.
7. Rapid refueling.
8. In-hull radioactive waste disposal facilities.

PHASE II.

Installation of the nuclear steam supply system design evolved out of the research and development program in a series of selected merchant ships.

PHASE III.

Assistance in crew training, design and construction of privately owned servicing facilities, ship design review, ship inspection, ship operation advisory and such other peripheral functions as necessary in order to insure the high reliability and high utilization of materials and labor required by deployment of the nuclear steam supply system.

[illegible] the conditions for federal support be as follows:

1. That the installation of the evolved nuclear steam supply system design be restricted to those ships having the following characteristics and capabilities:

   a. High power - in order to maximize the advantage of [illegible].

   b. Long trade route - in order to maximize the advantages of greater cargocapacity and lower nuclear fuel cost through increased reactor utilization.

   c. Improved cargo handling capability resulting in the reduction of in port time - in order to maximize the advantages of greater cargo capacity and lower nuclear fuel cost through increased reactor utilization.

2. That participating shipowners agree to the installation of a standardized nuclear steam supply system on a series of ships constructed on a multiple acquisition basis so that the economies of volume can be realized in both the production of the nuclear steam supply system and the construction of the ships.

3. That participating shipowners demonstrate that a viable commercial demand exists for a series of ships with the characteristics described in order to insure the degree of ship utilization necessary to economic competition with conventional installations.

These conditions are not designed to be an arbitrary set of impositions on shipping interests. First and foremost, they are the conditions necessary to economic parity with conventional ships of the same characteristics. Secondly, the dollar amount of public monies involved in such a program requires that the probabilities for success be maximized.

The final conclusion reached by this study is that an agency or department of the government be given the authority and [illegible] and responsibility necessary to the centralized direction that such a program requires and to put an end to the internecine squabbling within the government that is now prevalent and at least in part responsible for the state of confusion and disarray that exists in the maritime nuclear power program. In this connection, this study supports the recommendation of the former Secretary of Transportation that the functions of the Maritime Administration be transferred from their present position in the Department of Commerce to the Department of Transportation in order to eliminate the isolation of the maritime sector of government from the technology, requirements, policies and support of the national transportation system.

It is the considered opinion of this study that if such a program were vigorously pursued and adequately supported, the government would accrue hard economic advantages in the form of the reduction of balance of payments deficit, greater recapture of support dollars, higher tax revenues, amortization of support over a broader base and ships which would be an effective, modern auxiliary to the armed forces in time of national emergency.

The realism of present nuclear power economics in merchant ships cannot be denied. It is an expensive technology and must take its correct place on the list of competing national priorities. But it is also necessary to have equal respect for the realism of future maritime economics. While nuclear power cannot solve the present crisis in the United States merchant marine, failure to recognize the maritime intent of competing nations, failure to recognize the emergence of a new concept in trans-oceanic commerce and failure to grasp the transcendent impact of oil reserves depletion may well create a new and greater crisis in the future - that of being driven from the seas again by an uncompetitive technology.

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